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CONCEPTUAL DESIGN OF A ROTATING BREECH AUTOMATED AMMUNITION HAN--ETC(U)
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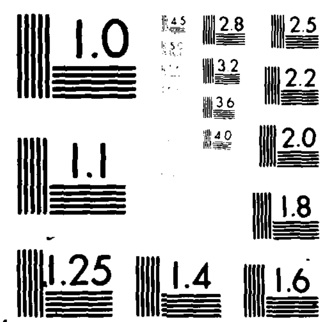

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14 February 1980

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CONCEPTUAL DESIGN of a ROTATING BREECH AUTOMATED AMMUNITION HANDLING SYSTEM

FINAL REPORT

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Prepared for

U.S. ARMY ARMAMENT
RESEARCH AND DEVELOPMENT COMMAND
DOVER, NEW JERSEY

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FINAL REPORT

Conceptual Design of A Rotating Breech and Automated Ammunition Handling System

Contract
DAAK10-79-C-0164

15 January 1980

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1.0 INTRODUCTION

1.1 BACKGROUND

The effectiveness of 155mm howitzers can be improved by a system that provides burst firing capabilities, increases the sustained firing rate and reduces manpower requirements. The purpose of this contract is to conceive such a system utilizing a rotating breech and an automated ammunition loading system.

It is desirable for a self propelled howitzer to be capable of firing a barrage of projectiles at a target before the enemy can disperse, seek cover, or detect and counter the fire. This would also enable the howitzer to fire at other targets or relocate to avoid counter fire. The rate of current manual loading and firing is limited by human strength and agility, and at some firing elevations by the time required to bring the cannon to a loading position. An automated mechnical loading system may be able to increase the rate of loading and firing, thus improving the effectiveness of the howitzer.

An automated system may also be desirable since manpower requirements would be reduced, freeing manpower for other tasks, or reducing the crew.

1.1.1 Current Loading

Currently the 155mm ammunition is loaded in two parts: a fuzed projectile and a propellant charge. The projectile has an eye at its tip to facilitate handling. Prior to loading the eye is unscrewed and replaced with a fuze. Currently, the propellant charges are contained in individual bags, which are tied together with straps. Prior to loading, the package is untied and the appropriate individual bags are removed (if any) so that the charge will propel the projectile the proper distance.

There are several different types of projectiles, projectile fuzes and propellants available, any combination of which may be required.

Current manual loading consists of the following steps:

- Choosing a projectile, projectile fuze and propellant charge.
- Removing the projectile, fuze and propellant from stowage.

- Attaching the fuze to the projectile.
- Adjusting the quantity (zoning) of propellant.
- Lowering the cannon to a load position. (If required)
- Opening the breech.
- Inserting the fuzed projectile into the breech.
- Ramming the projectile further into the breech.
- Inserting the propellant behind the projectile.
- Closing the breech.
- Elevating the cannon to a firing position. (If required)

1.1.2 General Concept

By utilizing the recoil energy of the cannon to rotate only a portion of the cannon, the breech can be automatically positioned to load quickly. The breech would return to the same loading position (relative to the cab) after firing, which would also be conducive to an automated loading system. The projectile and propellant charge will still be fuzed and zoned manually.

1.2 OBJECTIVES

The following are among the specified objectives of this project:

a. Fire 3 rounds in 10 seconds,
b. Fire 2 rounds per minute, sustained;
c. Provide manual back-up;
d. Capable of firing cannon launched guided projectiles ~~(CLPG)~~ manually;
e. Capable of operating at -50°F through + 160°F ambient temperature;
f. Capable of operating through 360° deg turret rotation and 0° deg to 70° deg cannon elevation.
g. Capable of handling rigid consumable case propellant;
h. Capable of handling future propellants,
i. Breech must withstand 60,000 psi and 2,500,000 lb force;
j. Design elements must be modular;
k. Designed for easy incorporation of future product improvements;
l. Provide appropriate ramming force;
m. Compatible with present and future fire control; and
n. Must be technically feasible.

o. System weight must not be excessive.

p. Space claim requirements within the envelope of the M109A2 self propelled howitzer.

q. Power consumption must not be excessive.

r. Must be reliable, available and maintainable.

s. Must be capable of safe operation.

t. Must not require excessive logistic support.

1.3 ASSUMPTIONS

The following assumptions were considered in the design of the automated ammunition handling system.

- 155mm diameter fuzed projectiles will vary in length from approximately 20" to 36".
- The propellant charges are contained in a combustion consumable case, 155 mm in diameter, 30" in length, which can be manually opened at one end.
- The propellant case is sufficiently strong to endure handling, but not strong enough to withstand ramming the projectile ahead of it into the breech.
- Any combination of stowed "ready" projectiles, projectile fuzes and propellants should be available in the automated mode.
- Projectiles can be manually fuzed and the propellant charges can be manually zoned while stowed.
- Hydraulic oil and DC electrical power are available to operate the ammunition handling mechanism.

2.0 SYSTEMS APPROACH

The primary functions of an ammunition handling system are to:

- o Contain and protect the ammunition
- o Interface with the resupply system
- o Elevate or depress the gun to the loading position
- o Select the projectile
- o Select and zone the propellent charge
- o Install the fuze
- o Set the fuze
- o Transport the ammunition to the breech
- o Load the breech (projectile, propellent & primer)
- o Return the gun to the firing position.

Currently, all of the above are manual operations performed with minimal mechanical assistance. The objective of this contract is to evaluate methods of improving the cost - effectiveness of the system through automation of some or all of the ammunition handling functions. This section will examine these functions from a systems viewpoint to define guidelines for system design.

2.1 SYSTEMS EVALUATION

Contain and protect the ammunition.

155mm projectiles vary in length from 20 to 36 inches and in weight from 96 to 125 pounds. The bagged propellent is contained in a consumable case shown in figure 2-1. One function of the ammunition handling system is to contain and protect the ammunition in a compact, efficient stowage rack that is accessible both for loading and resupply. Protection is particularly important for the fragile propellent cannisters, which must be protected from shock during both transport and loading to avoid propellent break up.

System physical constraints are illustrated in the vehicle constraint diagram, figure 2-2. As illustrated in the figure, the two primary areas potentially available for ready round stowage are the rear hull area (A) and the cab bustle (B). The primary advantage of stowing the ready rounds in the hull is that the center of gravity is lower, and this system has been successfully employed in casemate tank designs such as the Swedish "S" tank.

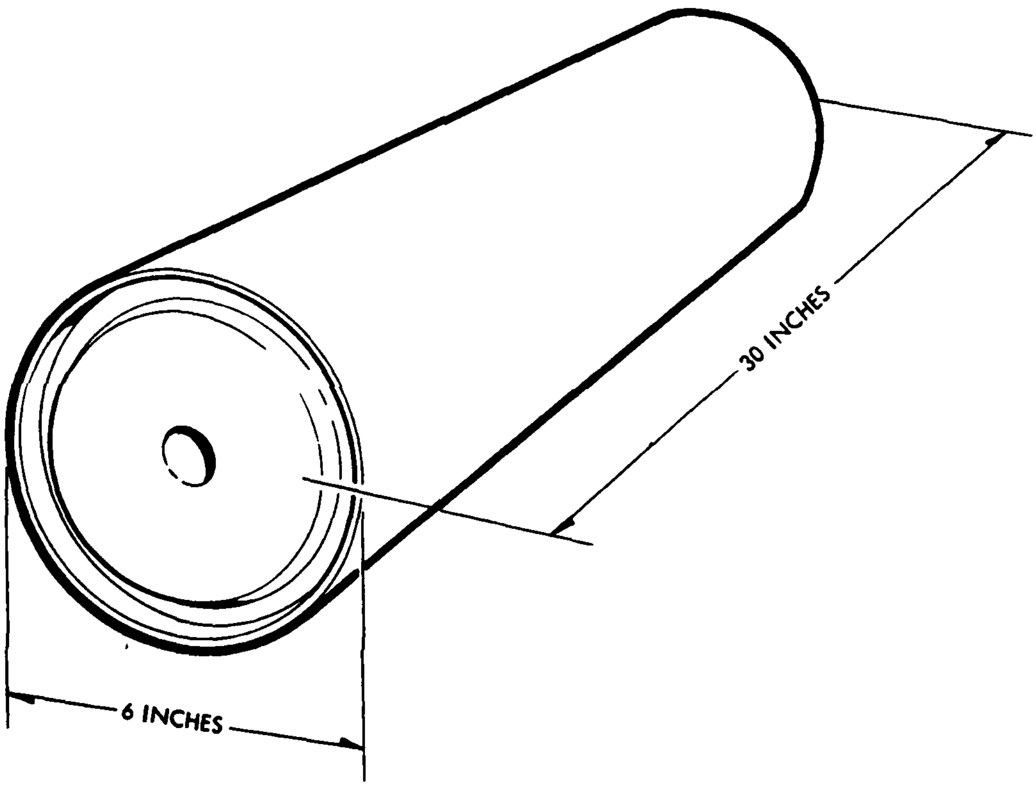


Figure 2-1 Propellent Canister

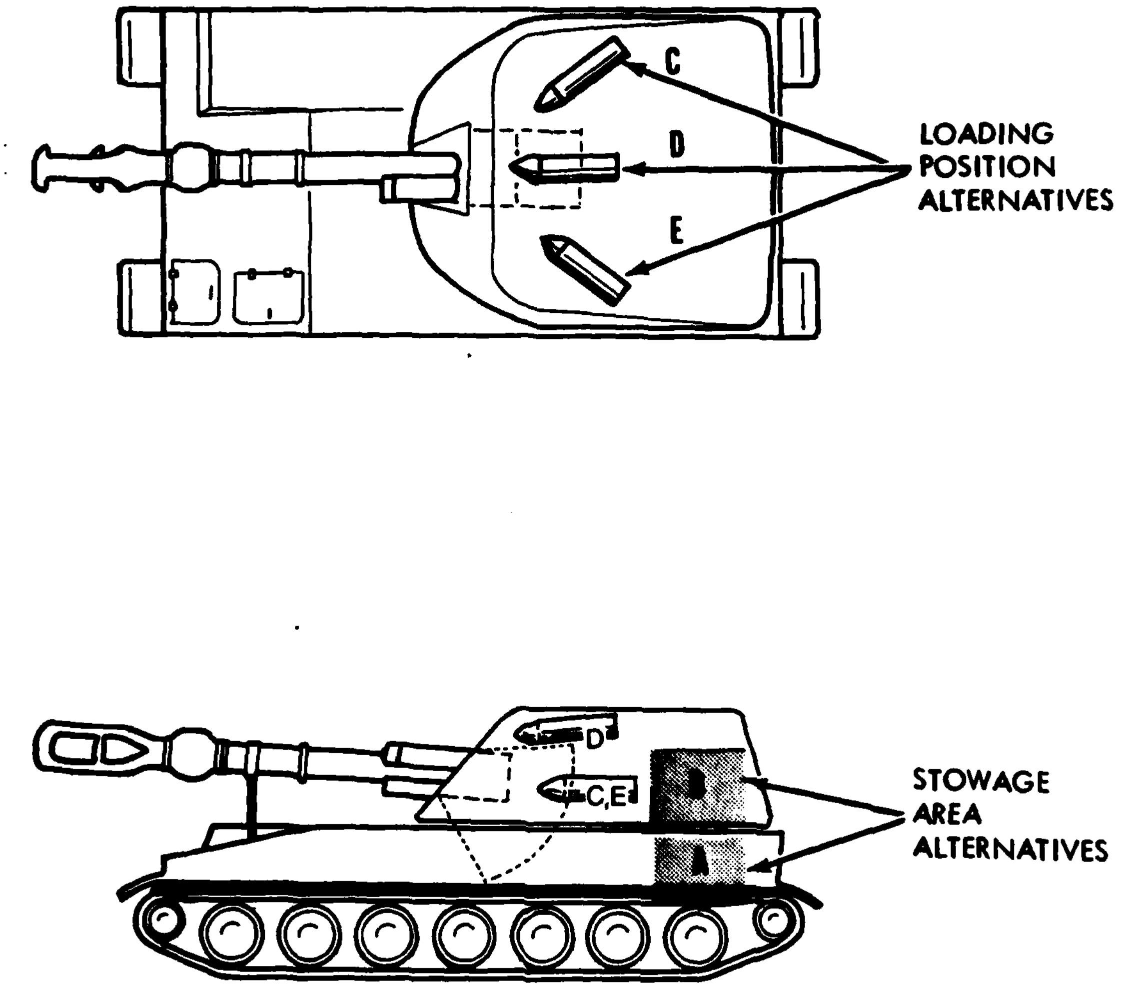


Figure 2-2. Vehicle Physical Constraint Diagram

For vehicles with a rotating cab, however, bustle stowage is clearly preferable, in that it avoids the problem of rotating the cab or ammunition to the azimuth firing position prior to loading.

Interface with the resupply system.

This requirement implies that the primary ammunition stowage area must be located in a position where access doors can be provided to facilitate resupply. Cab bustle stowage can meet this requirement by providing doors in the rear of the bustle.

Elevate or depress the gun to the loading position.

The rotating breech concept eliminates this requirement and requires only that the much smaller breech section of the gun be rotated to the loading position. The loading position must be located so that it is outside of the gun and recoil space at all gun elevations. Potential loading positions as shown in the figure are to the side of the gun (C or E) or above and to the rear of the breech (D). With the loading position to the side of the gun (C or E), the breech must be rotated in both azimuth and elevation to reload. With the loading position above the gun (D) only rotation in the elevation plane is required. All of these positions will be evaluated during concept development.

Select the Projectile.

Because of the variety of projectiles fired from a 155mm gun, some method - either manual or automatic - must be incorporated in the projectile feed system to allow selection of projectiles. Automatic selection can be achieved either by providing separate magazines and control gates for each projectile type, or by random intermixed stowage with the projectile type and location stored in the system memory for later retrival, as was done with the XM803 105mm automatic loader.

Select and zone the propellent charge, set fuze, install fuze.

Automatic zoning will probably require the development of new propellents, and automatic fuze installation will require the development of new fuze designs. Systems for setting the fuze automatically are currently under development. All of these items are beyond the scope of the present contract and will not be considered in detail, however, systems should be designed for compatability with further automation wherever possible.

Transport the ammunition to the breech.

The transport system is a major contributor to system complexity and system failure in existing automatic loaders such as the GCT and SP70. Transport design should be governed by the following design guidelines:

- o The path length between the stowage and loading positions should be as short as possible.
- o Design simplicity should be emphasized.
- o The number of transfers of ammunition should be minimized, since failure rates are particularly high at the point where objects are transfered from one mechanism to another.

Load the breech.

Hydraulic breech ramming mechanisms are also major contributors to system failure. Failure rates are especially high if the rammer is gun mounted and subjected to recoil shock. The ramming mechanism must be designed and mounted so that it is effectively protected from the shock of gun recoil.

Return the gun to the firing position.

The rotating breech concept eliminates this step, requiring only that the breech section be rotated to the closed position.

2.2 SUMMARY OF DESIGN GUIDELINES.

The following system design guidelines have been established to guide the design of the ammunition handling system:

- o The cab bustle is the preferred position for ready round stowage.
- o The stowage and transfer mechanisms should be designed to isolate the propellent cannister from shock to prevent propellent case break-up.
- o The loading position should be either to the rear and side of the gun, or to the rear and above the gun.
- o The system must be capable of differentiating between and selecting projectile type as required.
- o Ammunition transport path length should be minimized.
- o Design simplicity should be emphasized.

- The number of transfers of ammunition from one mechanism to another during loading should be minimized.
- Hydraulic mechanisms if used, should be isolated from gun recoil shock.

3.0 ROTATING BREECH CONCEPTS

The basic precept of the rotating breech concept is that the breech rotates to a position that is fixed relative to the cab, so that the ammunition can be transported to and loaded from a constant fixed position. This avoids the problems associated with systems that must locate the breech and orient the ammunition to the gun elevation angle prior to loading. Prior automatic loader concepts have achieved this by indexing the entire gun in elevation, a time consuming process that is not compatible with rapid fire requirements. The rotating breech concepts presented in this section rotate only the breech section of the weapon, permiting rapid loading rates capable of meeting the burst rate of fire required by modern artillery weapons. Three primary rotating breech concepts were developed during the course of the study. These concepts are:

- o A lever actuated dual axis spherical breech.
- o A gear actuated dual axis cylinder actuated single axis cylindrical breech.
- o A rotary hydraulic cylinder actuated single axis cylindrical breech.

This section describes the function and operation of these concepts, and evaluates the ability of the concepts to meet program objectives.

3.1 CONCEPT I - DUAL AXIS SPHERICAL BREECH - LEVER ACTUATED

This concept utilizes a spherical breech bearing that rotates horizontally and vertically to swing the breech to the reload position of 32.5 degrees from horizontal. The dual axis spherical breech uses the counter recoil energy of the gun to drive the breech in azimuth and elevation to a reload position that is fixed relative to the cab. The breech is guided to this fixed position regardless of the elevation angle of the gun by means of a front breech guide.

The breech concept is illustrated in figures 3-1 through 3-4.

- o The rotating breech (3) is a cylinder with a spherical center section supported by two cylindrical bearings.
- o The cylindrical bearings (4) support the breech during rotation and also transmit torque to rotate the breech . An anti-roll device (5) prevents the breech from rotating about the breech axis.

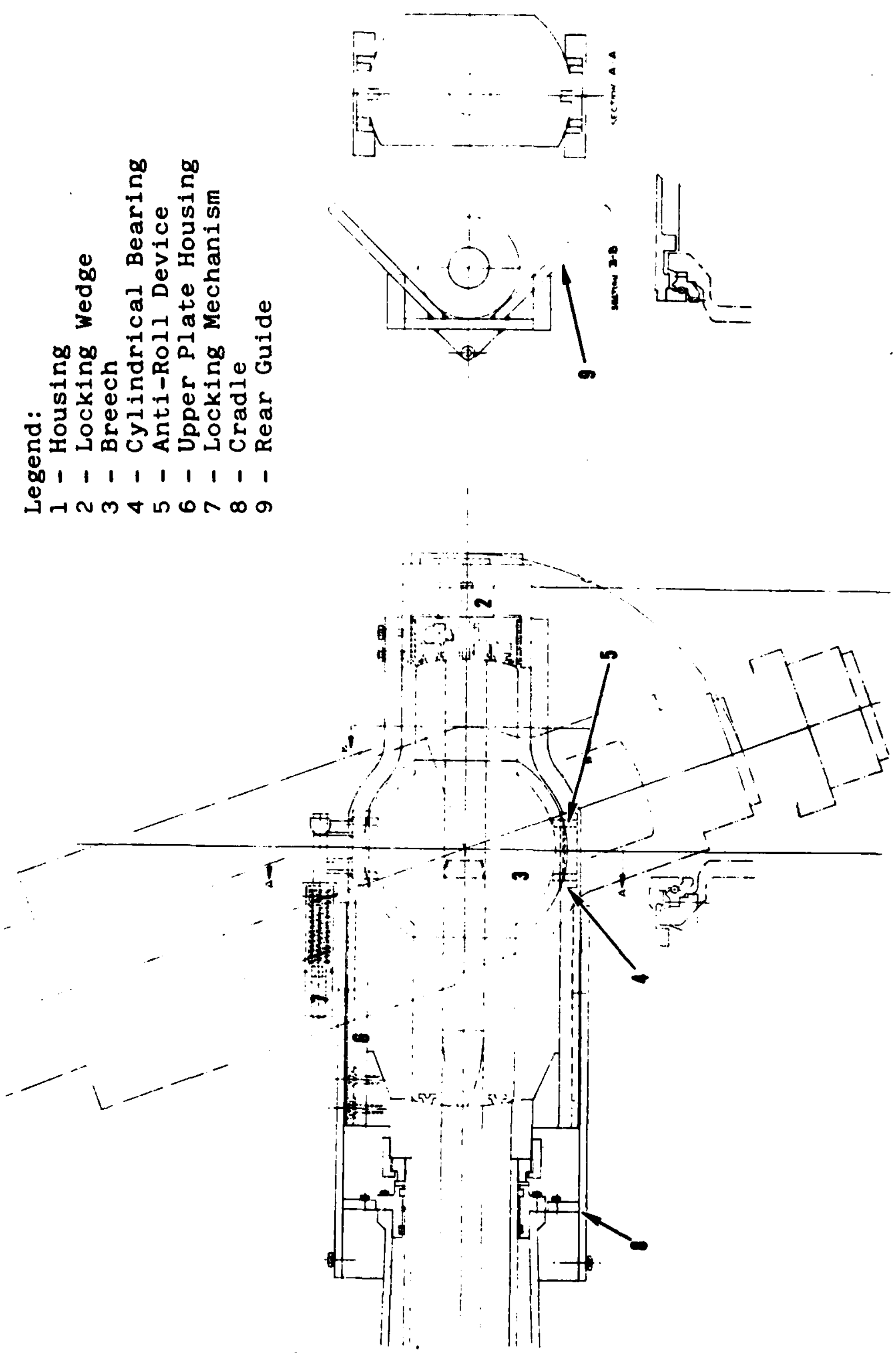


Figure 3-1 Concept I - Side View

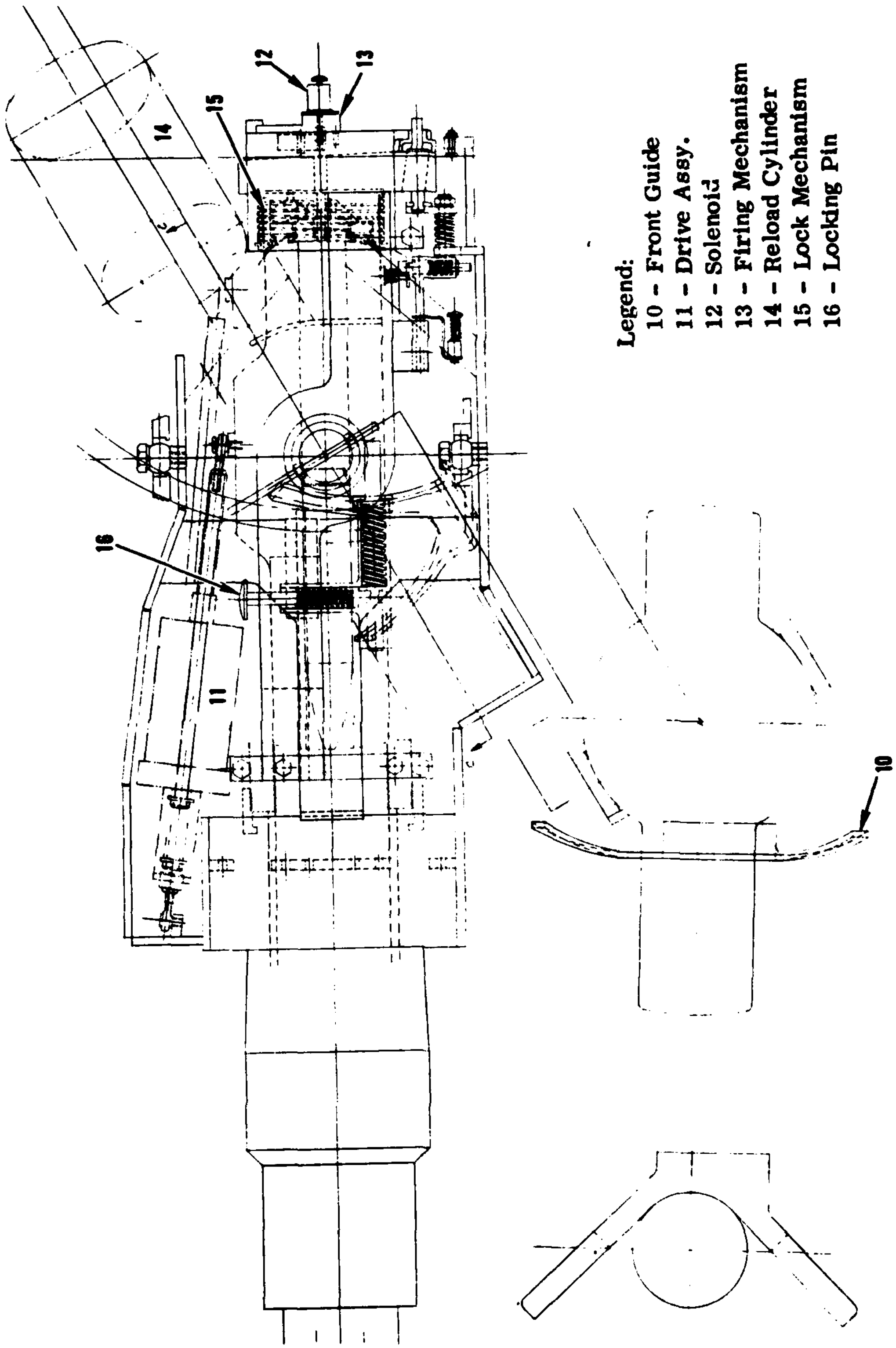


Figure 3-2 Concept I Plan View

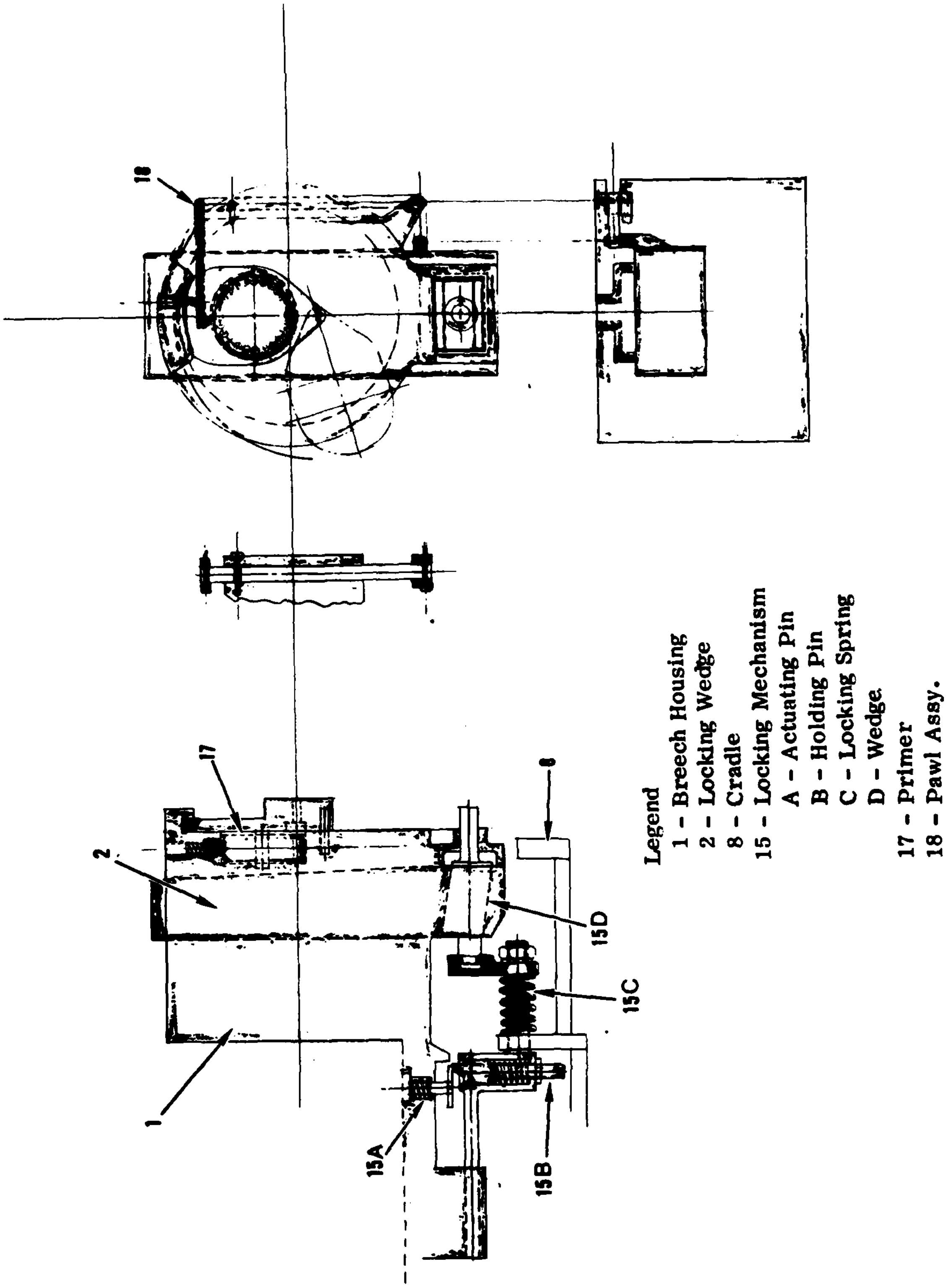


Figure 3-3 Firing Mechanism

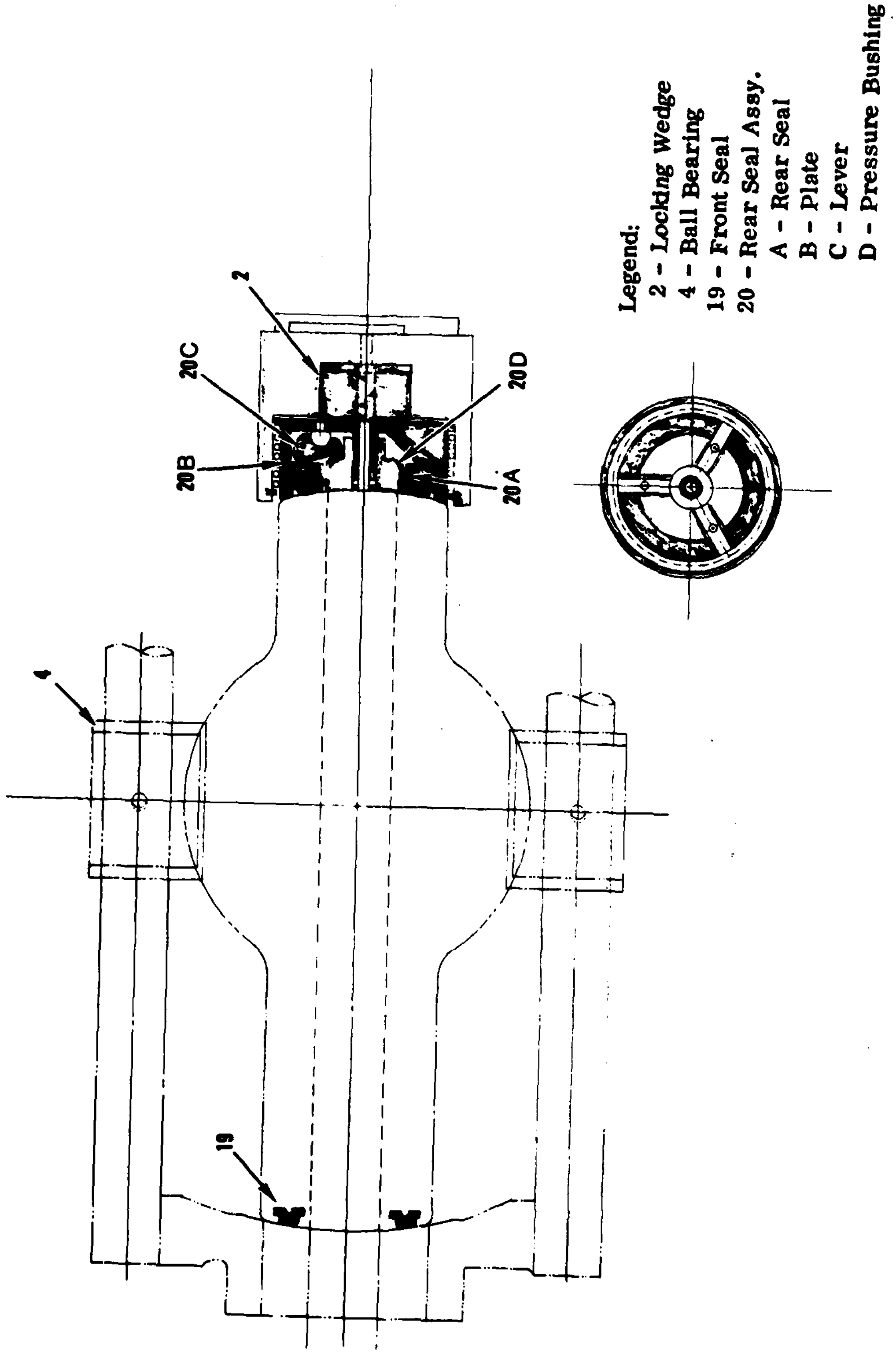
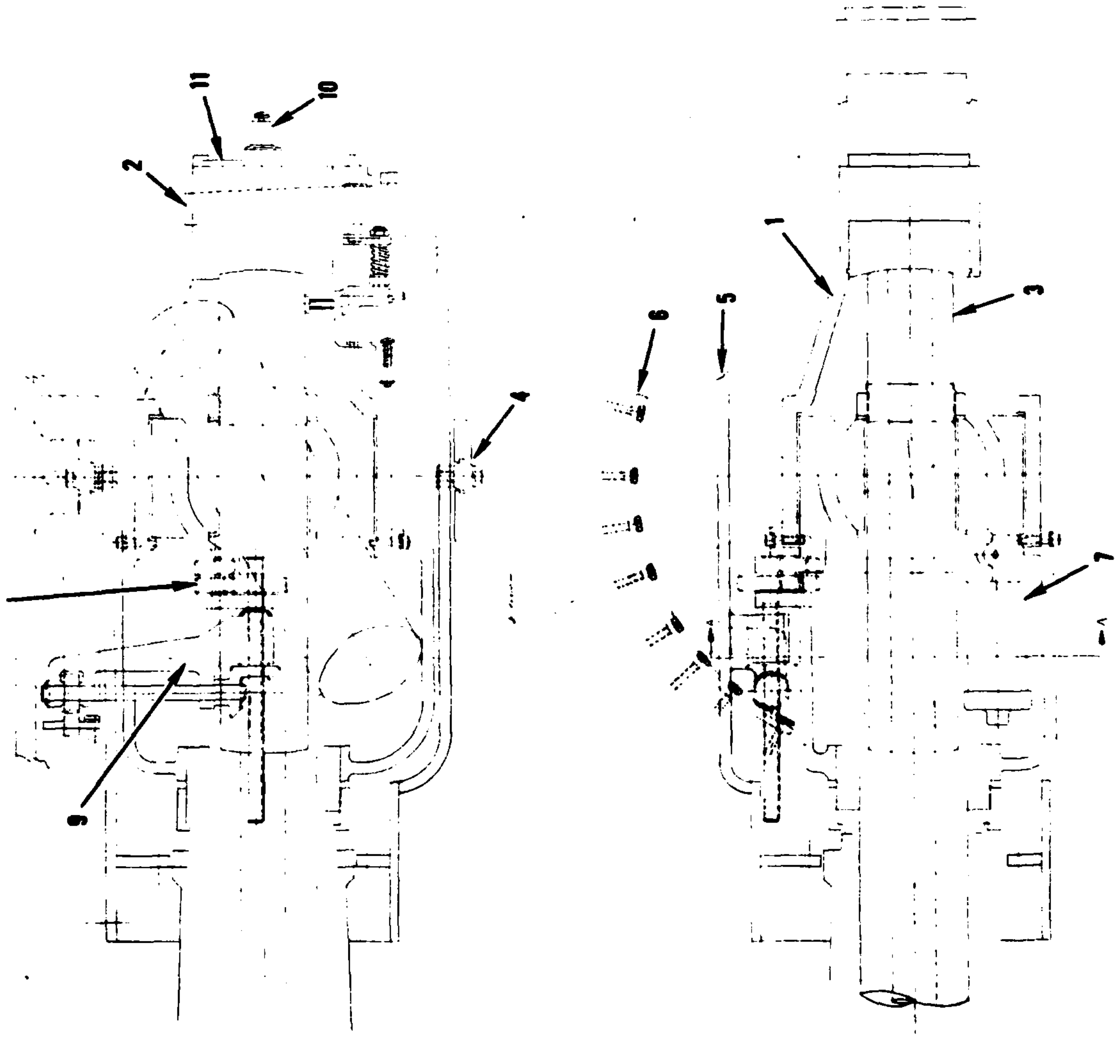


Figure 3-4 Breech Sealing Side View

Legend:
1 - Housing
2 - Locking Mechanism
3 - Breech
4 - Elevation Bearings
5 - Cradle
6 - Cab Gear Segment
7 - Elevation Mechanism
8 - Gear Assy.
9 - Cradle Mt. Gear Assy.
10 - Solenoid
11 - Firing Mechanism



Figures 3-5 Concept II - Plan and Side Views

Legend
12 - Breech Elevation Trunnion
13 - Elevating Housing

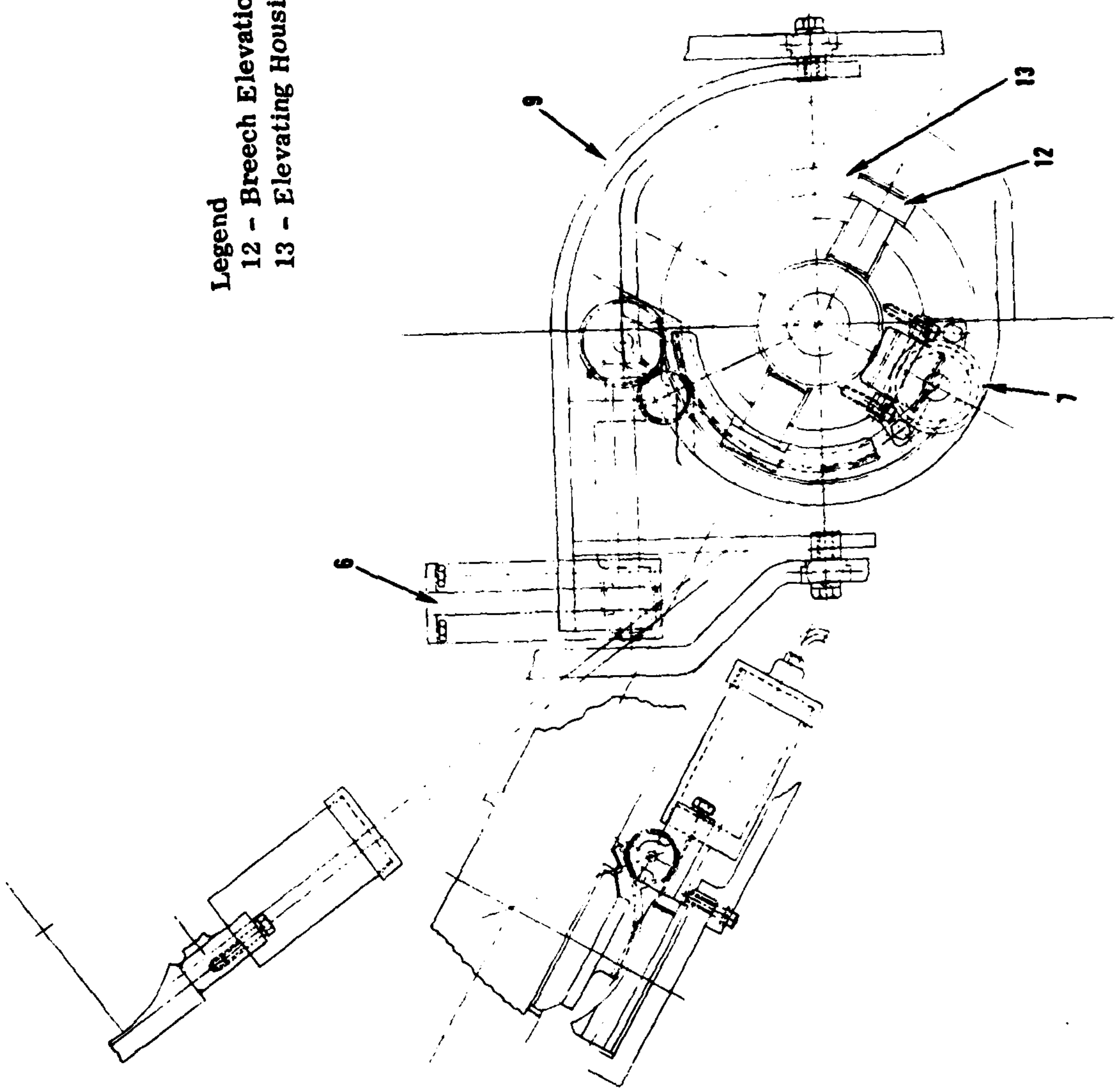


Figure 3-6 Sectional View - Gearing System

- A rear guide (9) attached to the breech housing (1) positions the breech into battery.
- A front guide (10), attached to the cab, is designed to align the rotating breech with the reload cylinder (14) regardless of gun elevation.
- The breech cradle (8) houses the breech ball bearings, breech housing, and breech.
- During counter recoil, the breech drive assembly is energized, the lock mechanism spring is energized, the breech locking mechanism pin is interruped allowing the anti-roll device to rotate the breech along the front breech guide and lock the breech in the reload position (14).

3.2 CONCEPT II - DUAL AXIS CYLINDRICAL BREECH - GEAR ACTUATED.

This concept uses an elliptical gear and pinion assembly to drive the breech to the reload position of 32.5 degrees from horizontal. As the gun is elevated or depressed, the breech swing axis is automatically rotated by the gear system. The gear angle of rotation is correlated up to 40 degrees of elevation angle such that when the breech swing occurs, the breech will be in its loading position. Above 40 degrees, the gun must be indexed for reload.

Figures 3-5 and 3-6 illustrate the conceptual operation of the breech.

- The breech chamber (3) is a cylinder which is attached to the breech housing (1) by means of the elevation trunnions (12).
- Actuation of the elevation mechanism (7) positions the breech into battery as well as positioning the breech to the reload cylinder. The breech will rotate about the elevation trunnions.

3.3 CONCEPT III - SINGLE AXIS CYLINDRICAL BREECH - ROTARY ACTUATOR

The rotating breech concept requires an ammunition loading position that is fixed relative to the cab and that does not intrude on the gun recoil space. The loading position for Concepts I and II is located in the hull to the side of the gun recoil space. Concept III loads ammunition from an elevated position above the gun recoil space. The primary advantage of this loading position is that the breech rotates only about the gun elevation axis, and a simple single axis breech bearing can be used. The breech is opened and closed by extracting the counter-recoil energy of the gun through an hydraulic accumulator.

The single axis breech concept is shown in figures 3-7 and 3-8. The breech assembly (2) is rotated to the reload position by a rotary hydraulic actuator (4). One of the design guidelines established during the system analysis task was that hydraulic systems must be isolated from the shock of gun recoil to ensure reliable operation. This is achieved in Concept III by mounting the breech rotary actuator on the gun cradle which does not recoil. Torque is transmitted to the breech through a sliding bar arrangement (8) which allows the gun to recoil with the breech guide bars sliding through the breech sleeve while the actuator remains stationary.

The gun cradle (7) is mounted on the gun elevation trunnions (11) which in turn carries all subsystems of the gun that rotate in elevation with the gun. The single axis rotating breech involves primarily the breech assembly, breech sleeve, breech housing and a cradle. The breech housing connects the rear of the breech to the gun tube; the breech assembly rotates through the breech housing to its reload position. The breech sleeve connects the hydraulic rotary actuator with the breech assembly. The breech assembly and the breech housing recoil through the breech sleeve together while the breech sleeve, hydraulic actuator and cradle remain stationary. The cradle supports all of these assemblies.

Breech Assembly

The breech assembly (figure 3-9) can be thought of as that portion of the current gun tube that is "cut away" to enable it to rotate about the trunnion to a fixed loading position. The breech assembly consists of the breech tube, guide bars and front seal. The breech tube receives the projectile and propellant charge from the loading mechanism and rotates back into battery for firing.

There are two parallel guide bars, one on each side of the breech assembly, that are attached to the front and rear of the assembly. These guides serve to accomodate gun recoil, to rotate the breech assembly to a loading position, and to prevent the breech from rotating about the gun tube axis. The guides pass through linear bearings in the breech sleeve assembly, which direct the breech motion. The guides slide through the linear bearings during gun recoil and transmit the torque required to rotate the breech to load when the gun returns to battery. There is also a circular seal assembly at the front of the breech assembly to contain the breech pressure during firing. The rear seal is contained in the breech block portion of the breech housing assembly. Various seal concepts are discussed in section 5.

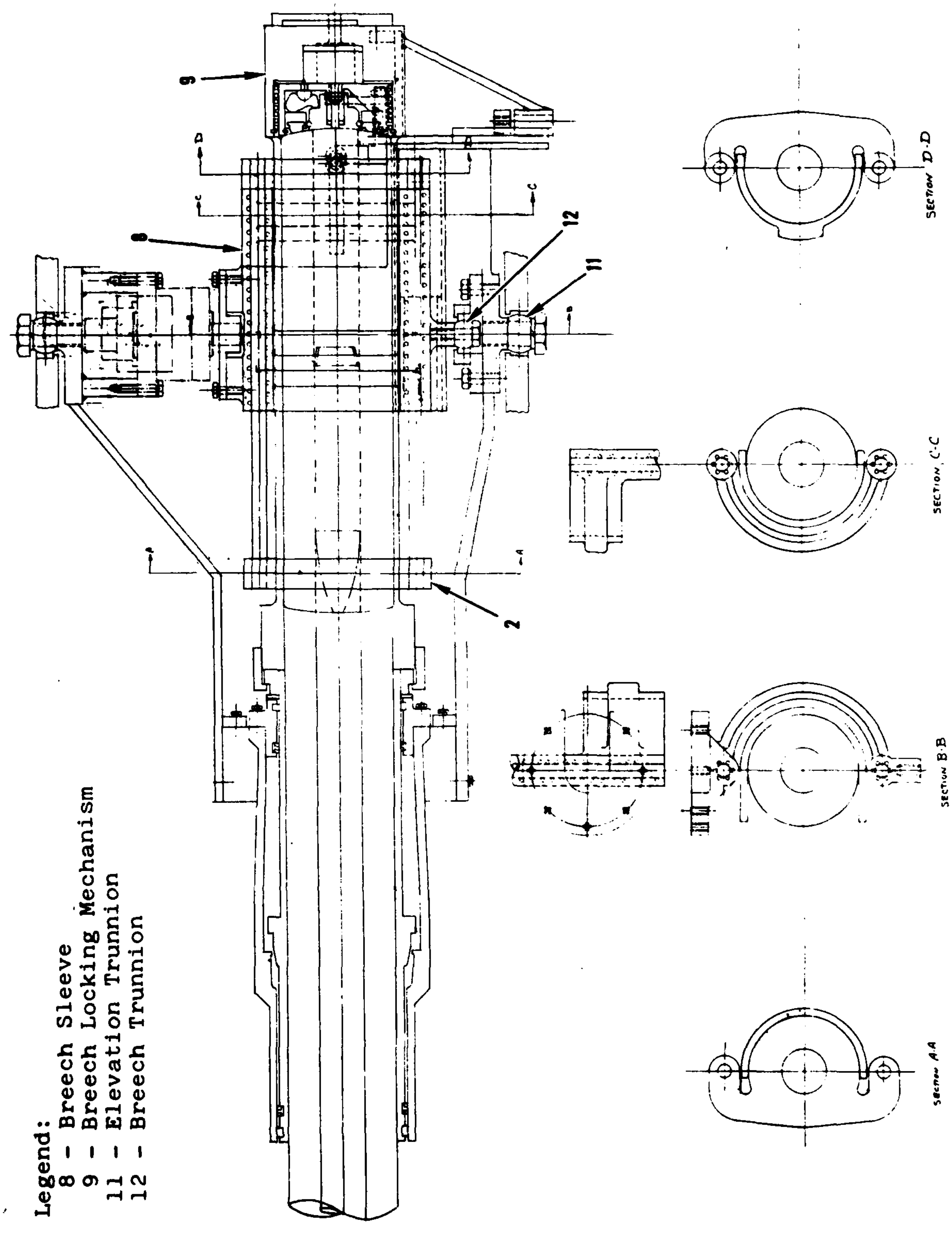


Figure 3-7. Concept II Plan View

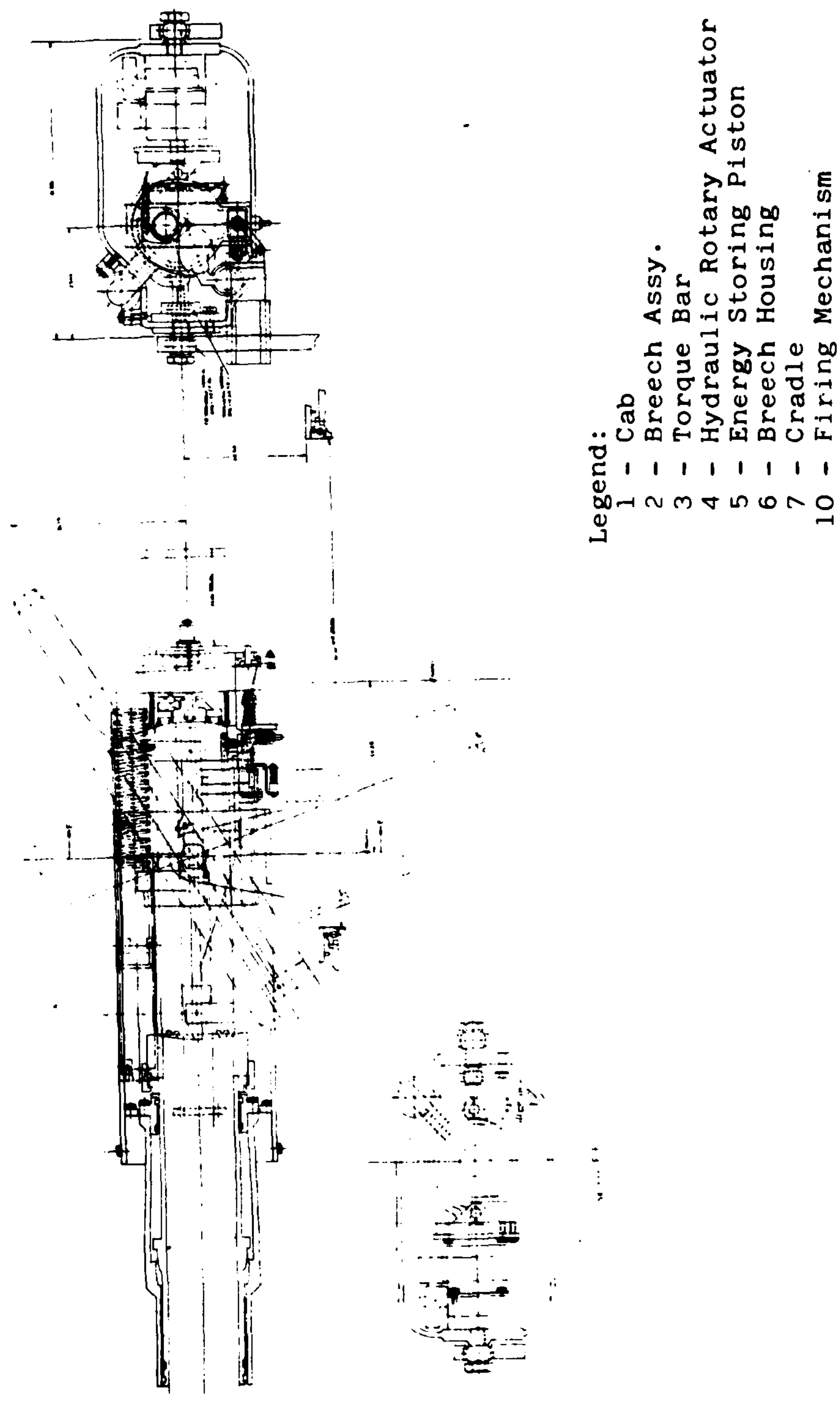


Figure 3-8. Concept III Side View

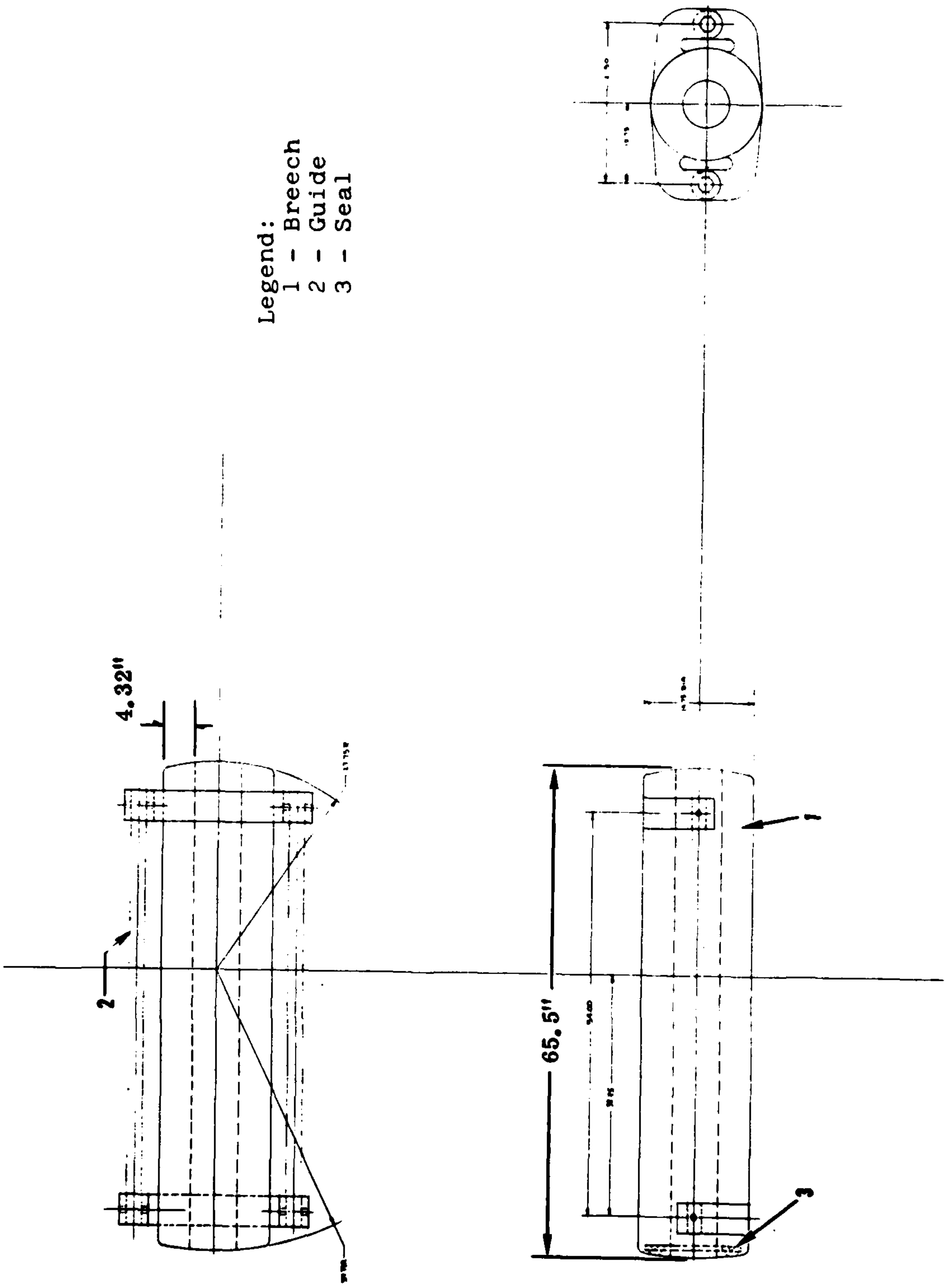


Figure 3-9. Concept III Breech Assembly

Breech Housing

The breech housing (figures 3-10, 3-11) contains the breech assembly and connects the gun tube to the breech block. The breech tube of the breech assembly is confined within the breech housing while the guide bars of the breech assembly extend along the outside of the breech housing. The breech assembly rotates through the breech housing to its loading position. The breech housing is always aligned with the gun since the front of the housing is threaded to the main gun tube.

The breech block is attached to the rear of the breech housing. For automated loading and firing, the block remains bolted to the housing. However, for manual loading and extracting rounds, the block can be split away from the housing to load the projectile and propellant from the rear.

The breech block is described in more detail in a subsequent section.

Breech Sleeve

The breech sleeve (figure 3-12) guides the motion of the breech assembly. The breech sleeve encages the breech housing and captures the breech assembly guide bars with linear ball bearings. This allows the breech and breech housing to recoil without the breech sleeve and its attachments.

The breech sleeve also has a bearing on one side that aligns with the trunnion. On the opposite side, it has a coupling flange that mates with the hydraulic rotary actuator output spline, which is also in line with the trunnion axis. This union couples the hydraulic actuator to the breech.

Hydraulic Rotary Actuator and Control System

The breech is rotated to its loading position with a hydraulic rotary actuator. The actuator requires approximately 3000 psi hydraulic pressure to operate, which is generated through the recoil energy of the gun. A schematic of the hydraulic system is shown in figure 3-13.

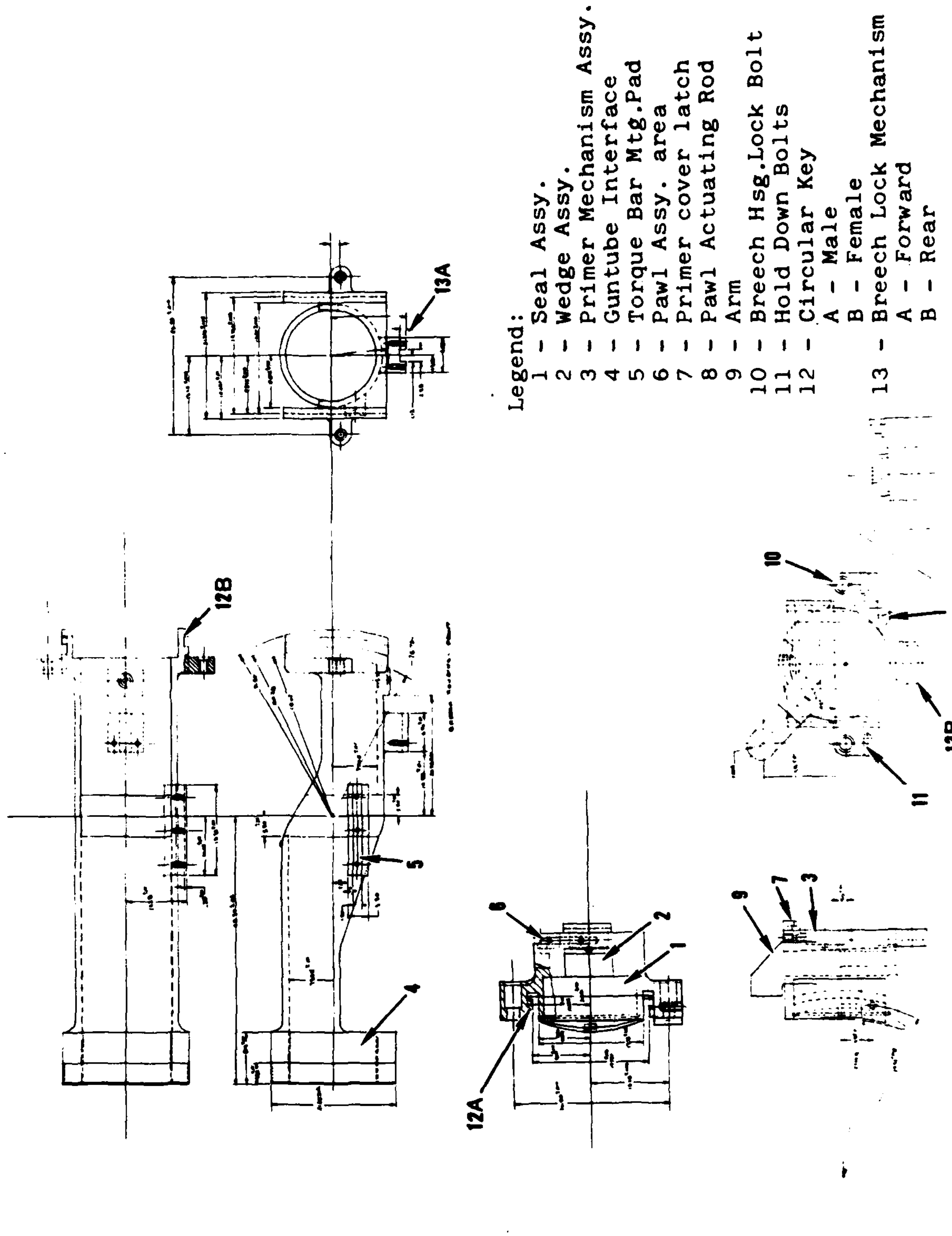


Figure 3-10. Concept III Breech Housing - Split

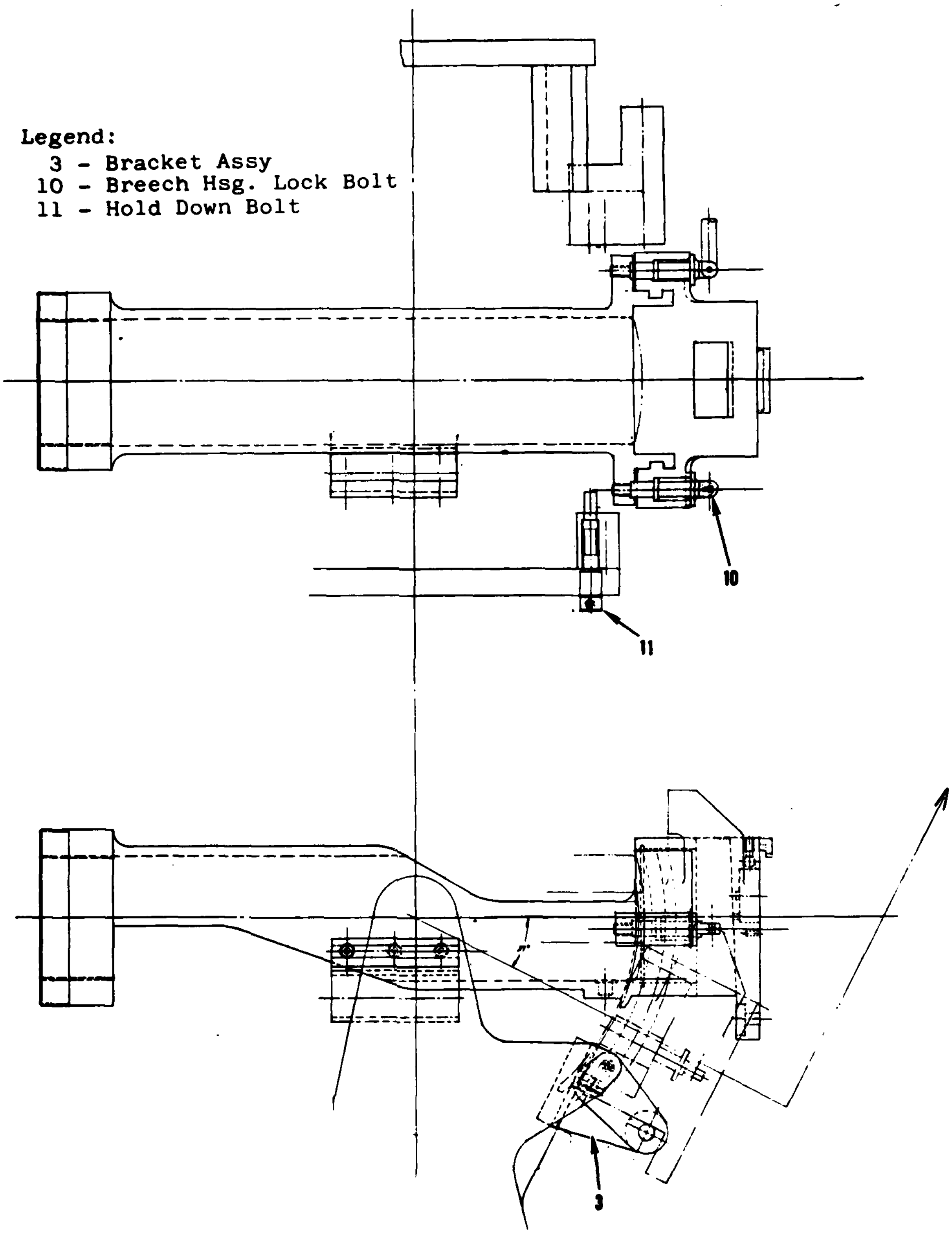
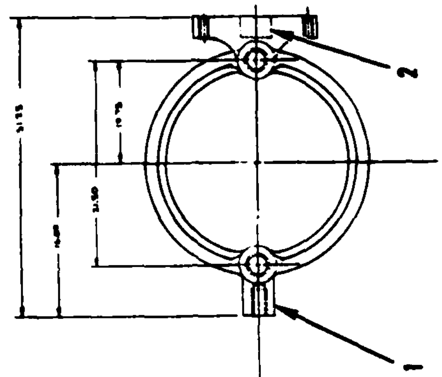


Figure 3-11. A Concept III Breech Housing - Split

Legend:
1 - Loading Trunnion Mount
2 - Spline Coupling Area
3 - Recoil Guide



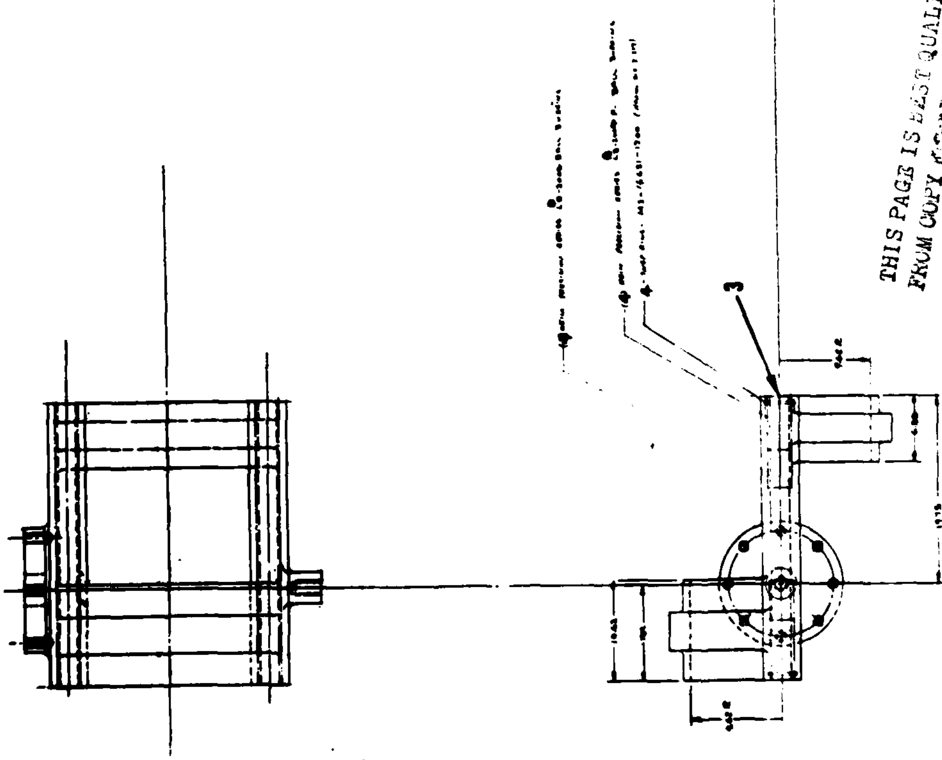


Figure 3-12 Concept III Breech Sleeve

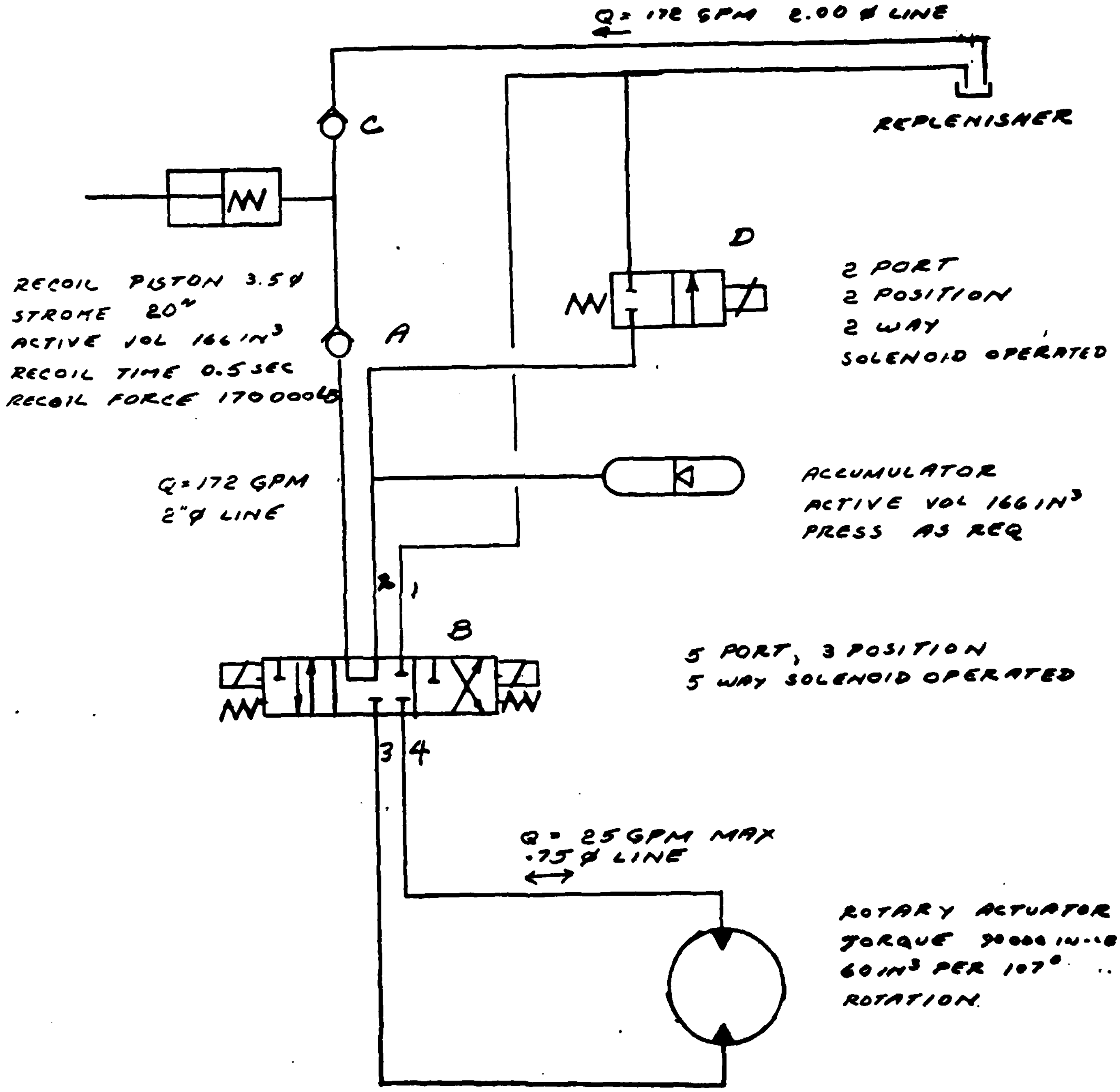


Figure 3-13 Hydraulic Schematic - Rotating Breech

The accelerations and motions of the breech are controlled by a logic circuit to minimize the time required to open and close the breech. This circuit is an integral part of the fire control circuit. The position of the gun elevation relative to the fixed loading position is continuously monitored to tailor the hydraulic input to the actuator. The control logic of the breech assembly also monitors the actual position of the breech to ensure the proper sequence of operation. This automated control system can also be overridden to manually control the hydraulic operation of the breech through some type of control lever. The weapon cannot be fired while the breech is manually controlled.

The output of the logic control circuit is amplified to drive a servo valve switch which in turn powers the vane type hydraulic actuator. A schematic of the breech control system is shown in figure 3-14.

Breech Block

The breech block is attached to the rear of the breech housing and contains the breech locking and firing mechanism and the rear breech seal.

The locking mechanism (figure 3-15) includes the locking wedge, primary wedge, stop, locking spring, actuating pin, interrupter and holding pin. The locking mechanism wedges the rear breech seal portion of the breech block against the breech, sealing the breech.

The locking wedge is driven by a locking spring through the primary wedge. The movement of this locking spring is controlled by actions of the actuating pin, holding pin, interrupter and stop. These functions are described in the Operation Section.

The firing mechanism consists of a latch cover, primer assembly, pivot pin, pawl assembly and solenoid. The locking wedge drives and is linked through an actuating rod to a pawl assembly that indexes the primer assembly. The solenoid fires the primer.

The rear sealing mechanism is described in section 5.

Cradle

The cradle (figure 3-16) houses all of the rotating breech assemblies, which include the breech, breech housing, breech sleeve, hydraulic rotary actuator and hydraulic accumulator. It

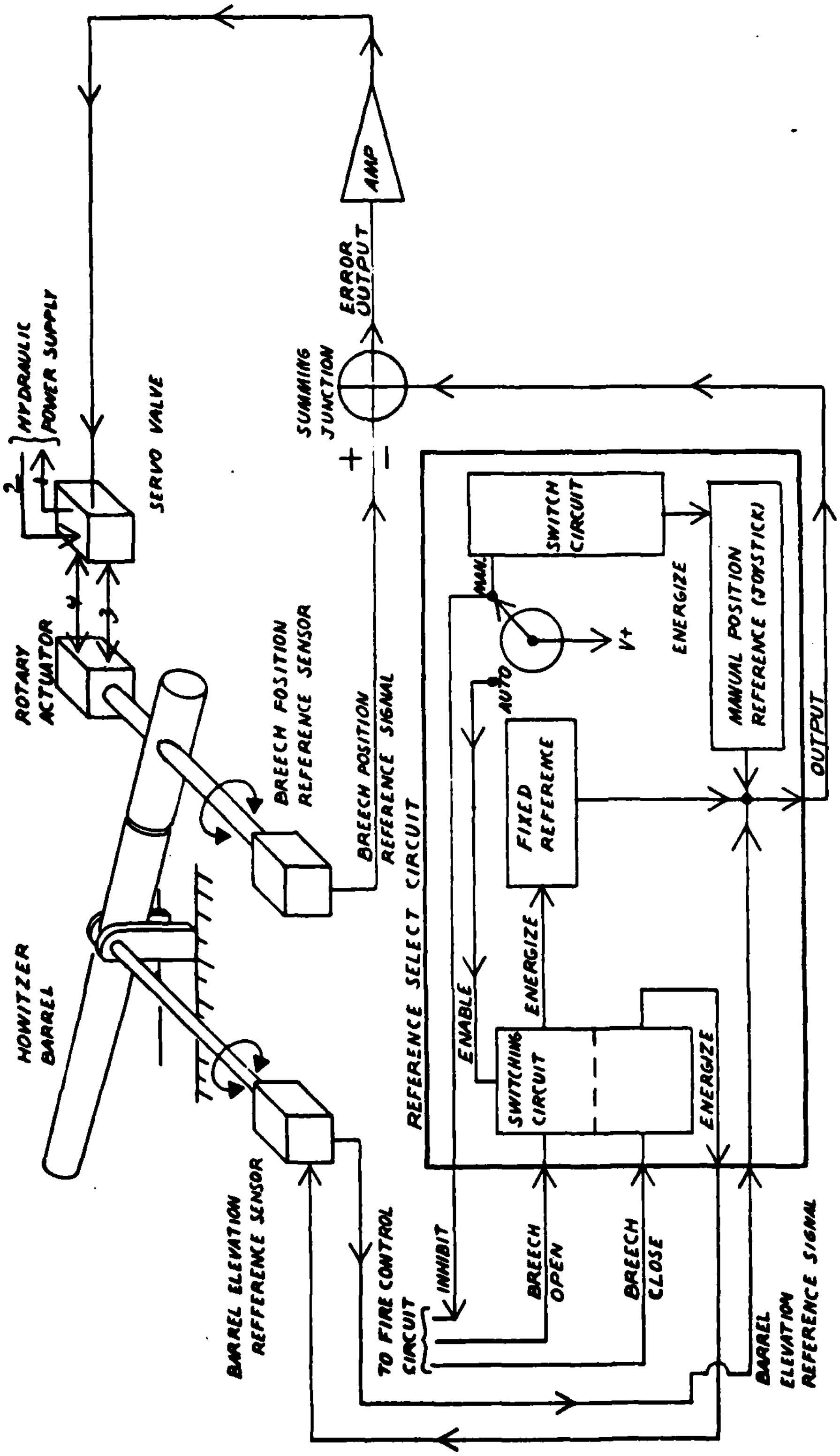


Figure 3-14 Breech Control

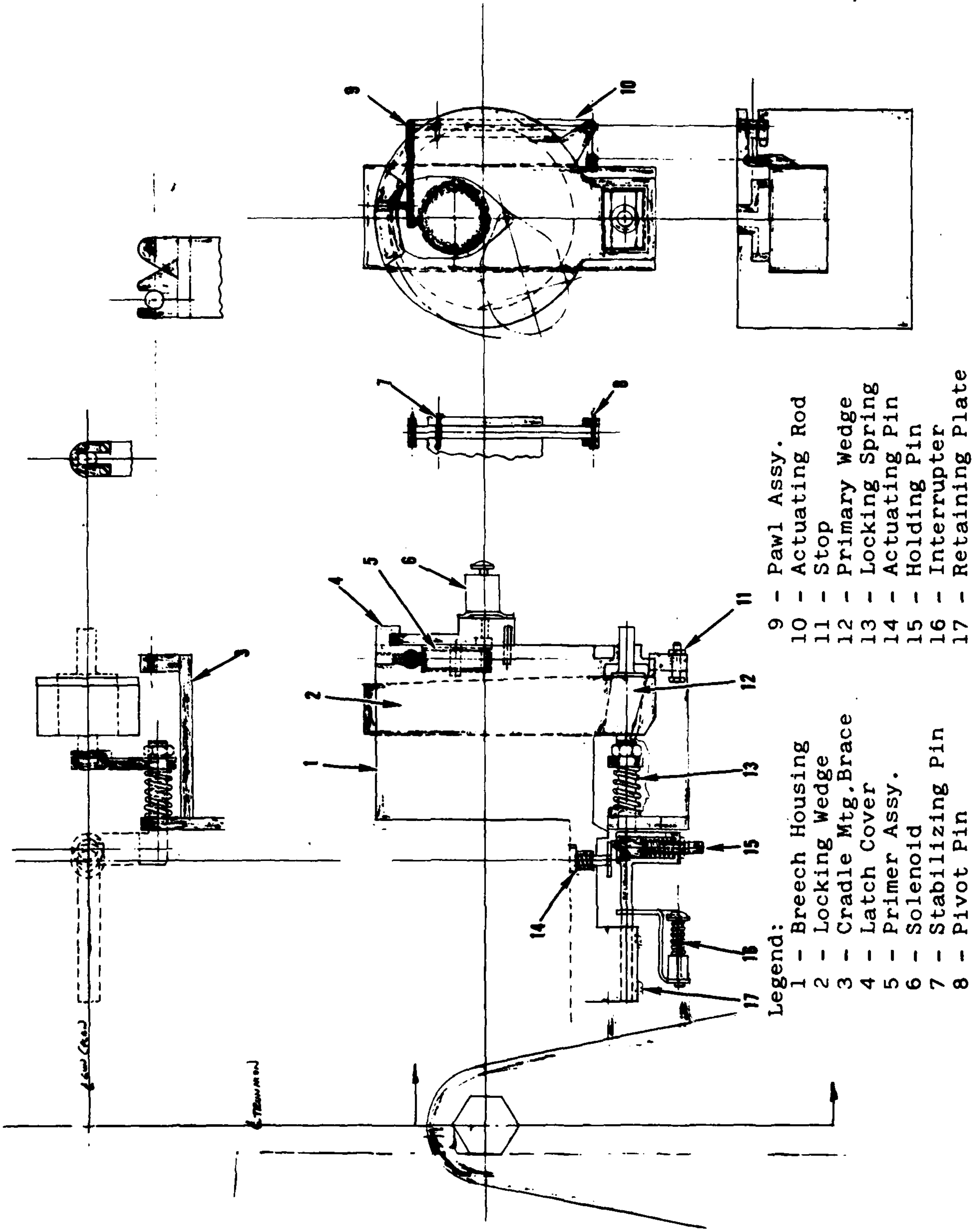


Figure 3-15. Concept III Breech Locking and Firing Mechanism

Legend:
1 - Gun Tube Pads
2 - Torque Brkt.
3 - Piston Assy Pads
4 - Hyd. Rot.Pwr. Pkge.
5 - Anchor

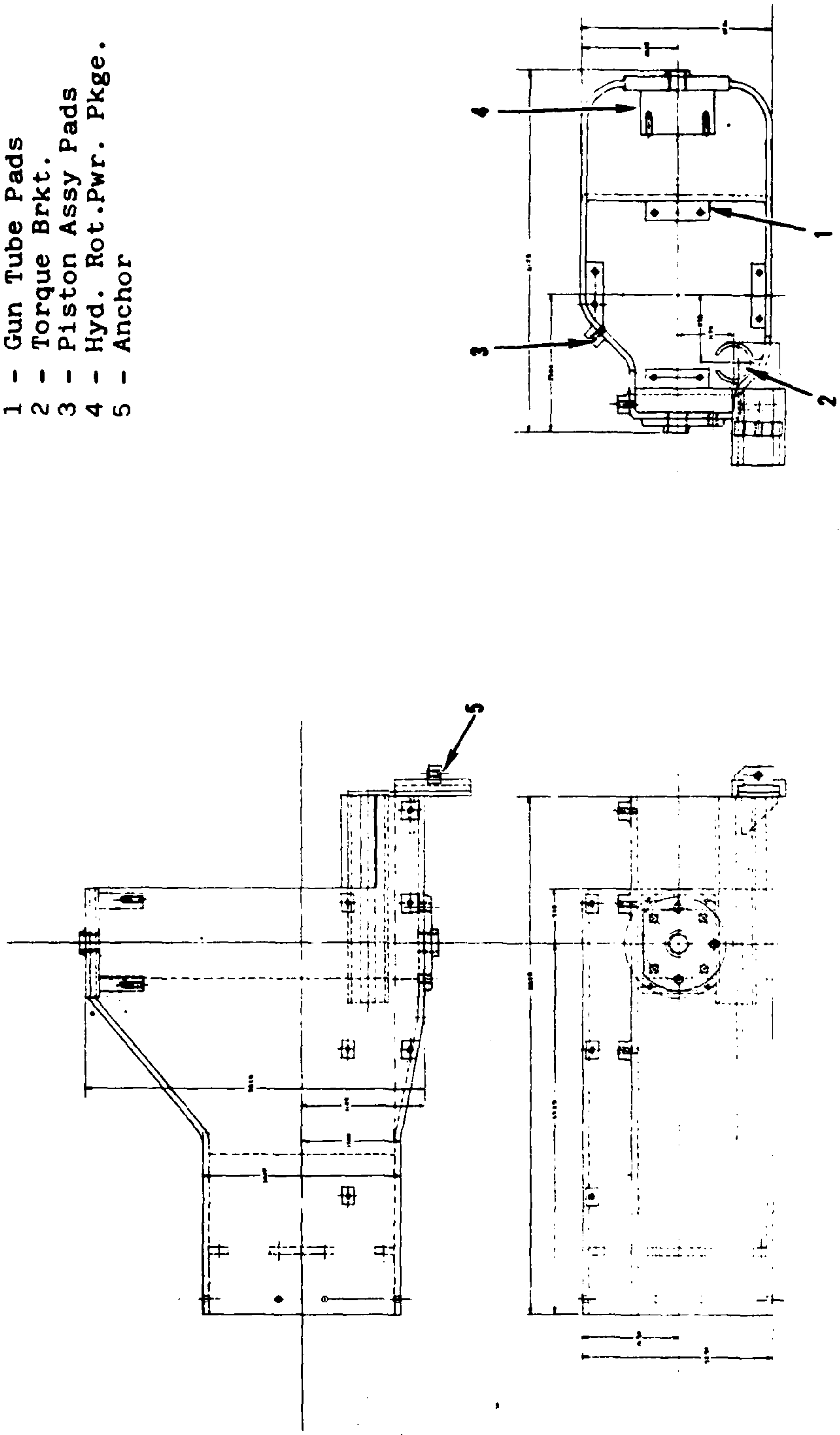


Figure 3-16. Concept III Cradle

3-16

is bolted to the gun mount and pivots about the trunnion. The cradle also has a torque bracket that guides the torque arm mounting pad of the breech housing to counter axial gun rotation during recoil.

The hydraulic actuator is mounted on one side of the cradle and rotates about the same axis as the trunnion. The breech sleeve is bolted to the hydraulic actuator on one side and is pivoted through the cradle on the other, all aligning with the trunnion axis.

The cradle also has an anchor plate which guides the breech block when it is split away from the breech housing for manual reloading.

Hydraulic Accumulator

The hydraulic accumulator harnesses and stores the counter recoil energy of the gun to power the rotating actions of the breech. During counter-recoil, an arm on the breech housing engages the spring-loaded piston on the hydraulic accumulator and pressurizes the oil through one-way valves.

Rotary Breech Operation

At the onset of firing, the gun tube begins to recoil. The breech and breech housing slide through the guides of the breech sleeve. As the gun reaches its furthest recoil, the interrupter on the breech block portion of the breech housing encounters a stop which withdraws the wedging mechanism that seals the breech.

As the gun counter-recoils, an arm on the breech housing engages the hydraulic accumulator to pressurize the hydraulic fluid. When the gun reaches battery, part of this pressurized fluid is valved to the rotary hydraulic actuator which rotates the breech to a load position. When the breech rotates to the load position, the actuating pin of the breech locking mechanism springs up, allowing the spring loaded holding pin to latch the cocked locking spring.

After the breech is loaded, it is rotated back into battery with the remaining pressurized fluid in the accumulator. As the breech reaches its battery position it depresses the actuating

pin of the locking mechanism, unlatching the locking spring which in turn wedges the breech block to seal the breech. The locking wedge activates the linkage of the primer pawl assembly which indexes the primer assembly to ready an active primer.

The gun is now ready to fire via the firing solenoid.

The breech block can also be separated from the breech housing to facilitate manual loading or extracting rounds in the breech from the rear. The breech block is bolted (figure 3-11, item 10) to the breech housing and is keyed to it through a circular key (12). When the gun is elevated 27° hold down bolt holes in the breech block align with hold down bolts in a bracket assembly fixed to the trunnion support. The hold down bolts are then secured to the breech block to support it. The breech housing lock bolts are then removed and the gun depressed to 0° for loading, leaving the breech attached to the bracket assembly. After manually loading the breech, the above sequence is reversed to reconnect the breech block and breech housing.

3.4 CONCEPT EVALUATION

The three preliminary concepts described in section 3.0 are evaluated on a comparative basis in this section. All three concepts appear potentially capable of meeting system requirements; however, each concept has strong and weak points that could potentially affect system performance.

3.4.1 Performance

The primary advantages of Concept I result from the low reload position which permits a lower cab height and better manual back up loading than is possible with Concept III. The primary disadvantage of this concept is that it allows uncontrolled and variable motion of the breech during the reload cycle, and requires a complex spherical breech bearing.

Concept II is similar to Concept I but corrects some of the shortcomings of the prior concept. By adding a gear section drive to rotate the breech about the longitudinal axis, the breech bearing can be rotated to the correct angle prior to firing, and a simplified bearing assembly can be used. The primary disadvantage is that these improvements are achieved thru the addition of a non linear gear system, which increases system cost and complexity.

Concept III employs a single axis breech rotation system which simplifies breech bearing design, requires less cab space for breech motion, and does not require a gear breech drive train. This single axis motion of the breech is achieved by employing a high reload position above the gun recoil arc. Disadvantages of this concept are that it requires additional cab height to accommodate the overhead reload system and that this also results in a system that is difficult to feed.

3.4.2 Reliability - Concept Assessment

Concept I

This concept utilizes counter recoil energy to position the breech for reloading. The positioning is accomplished by rotating the breech about two axes. Motion of the breech is controlled by the anti-roll device and the breech guides which direct the breech to the load position during counter recoil where it is locked to the loader. When loaded, the remaining energy stored in the breech drive assembly is used to reposition and lock the breech for firing.

This concept imposes high forces on the guides due to rapid breech block motion in two planes. This will necessitate massive supports for the guides to prevent the breech mechanism from jamming and/or misaligning during breech opening and closing. Comparing the complexity of the three concepts, this concept is less complex than Concept II but more complex than Concept III.

Concept II

Concept II utilizes counter recoil energy to position the breech for reloading and for firing. This concept is similar to Concept I except that an elliptical gear and pinion assembly positions the gun for firing enable the designers to utilize a cylindrical breech block bearing rather than the more complex spherical breech block bearing of Concept I. The gear train used for this system is not operational for gun elevations above 40^{o} and requires gun depression to 40^{o} to initiate the loading sequence. This concept is considered the most complex of the three proposed concepts.

Concept III

This concept elevates the rear of the breech to interlock with an overhead loader. Energy used to position the breech is derived from the counter recoil energy which rotates the breech on pinion bearings to the proper position for loading. The rotary motion of the breech is the least complex of all concepts and, therefore, considered most promising of the three proposals.

3.4.3 Human Factors and Safety Evaluation

Recommended Concept

Concept III, the single axis cylindrical breech concept, is recommended from the human factors and safety viewpoint because:

1. There is no azimuth offset when the breech is rotated to the loading position. This will result in less cab interior space being used for breech movement, thereby providing more crew workspace.

2. Because the breech will not be moving in azimuth, a less complex guard will be required to protect crew members from being injured by the breech as it moves from battery *to the loading position.*

Normal and Unusual Operating Conditions

1. Under normal conditions, loading, ramming and priming 155 mm rounds will be done automatically. This will allow the crew members to stand clear of the breech mechanism and gun recoil area while the 155 mm howitzer cannon is loaded and fired.

2. Under unusual conditions, e.g., loading and firing the 155 mm howitzer cannon when vehicle power is not available, and removing an unfired round from the cannon, the crew must take the precautions contained in the appropriate sections of the vehicle operator's *manual* (*ref.* TM 9-2350-217-109, Operator's Manual for Howitzer, Light, Self-propelled: 155 mm, M108 (2350-440-8810) and Howitzer, Medium, Self-propelled: 155 mm, M109 (2350-440-8811).

Special Safety Precautions

1. Stored mechanical energy should be protected, by interlock, from accidental actuation.

2. If crew-operated controls are provided for power-operated breeches, the controls should be located away from the breech to protect personnel when the breech is in operation.

CONCEPT EVALUATION SUMMARY

Concept I

Favorable	Unfavorable
Permits relatively low cab height.	Allows uncontrolled, variable breech motion during reload cycle.
Low reload position for better manual back-up loading.	Requires complex spherical breech bearing.
	Large counteracting forces at breech groove and guides present potential jamming problem.
	Dual axis breech motion requires large cab space.

Concept II

Favorable	Unfavorable
Breech motion controlled during reload cycle.	Employs complex non-linear gear
Employs simplified single-axis breech bearings.	Dual axis breech motion requires large cab space.
Pre-positioning of breech bearing in one axis requires frewer motions during critical reload cycle.	Potential for excessive gear wear
Permits relatively low cab height.	
Low reload position for better manual back-up loading.	

Concept III

Favorable	Unfavorable
Breech motion controlled during reload cycle.	Requires relatively high cab height.
Employs simplified single-axis breech bearings.	High reload positions results in difficult manual back-up loading.
Single axis breech motion requires less cab space.	

Table 3-1.

4.0 AUTOMATED LOADING CONCEPTS

The function of the automated loader is to transport the projectiles and propellants from the stowed position to the breech loading position. Both fully automated and manually assisted concepts are presented in this section. Loader concepts are evaluated in section 4.3, and the recommended loader and rotating breech concepts are described in more detail in section 5.0.

4.1 GENERAL DESIGN CONSIDERATIONS

The configuration and location of the loading mechanism depends heavily on, the design of the rotating breech. Since the single-axis rotating breech with an overhead feed was selected as the most promising concept, only loading mechanisms compatible with that system were considered. In addition to meeting the specific objectives of this project, the following were considered.

4.1.1 Crew Safety

Crew injuries could result from the detonation of ammunition while stowed or during a loading transfer. Therefore, the stowage and transfer mechanisms should securely and positively control the rounds at all times to prevent their uncontrolled movement or release during vehicle transport, cannon firing or transfer to load. Propellants and projectiles could also be detonated if struck by enemy fire; therefore, stowage systems capable of isolating the rounds with armor and relieving pressure/heat build-up are desireable. Moving parts of the loading system should be covered or away from the normal operating space of the crew to prevent injury. The loading system should not obstruct the movements of the crew.

4.1.2 Reliability, Availability and Maintainability

The loading system should be highly reliable and easily maintainable. Therefore, the system should utilize simple mechanical movements, few components, simple control logic and standardized components.

4.1.3 Loading Time

Since one of the main objectives of this project is to fire rounds quickly, the ammunition loading time is critical. Therefore, short, syncronized, simultaneous movements are desireable.

4.1.4 Support Logistics

To reduce the frequency of reloading, large stowage areas of "ready" rounds are desireable. However, this must be weighed against the increased hazard of locating more ammunition near the crew and weight/space considerations versus reloading logistics.

4.2 LOADER DESCRIPTIONS

The task of loading the cannon consists of transferring a projectile and propellant charge from stowage and inserting each into the rotated cannon breech. Only loading mechanism designs that loaded the projectile and propellant separately were considered, in order to minimize cab height.

In the loader descriptions that follow, only the recommended one is described in detail since shortcomings and deficiencies in refining the other concepts pointed toward improved designs.

4.2.1 Three Round Rotating Cylinder (Figure 4-1 & 4-2)

The three-round reload cylinder concept consists of a carrier containing six tubular chambers evenly spaced around a common axis of rotation. Projectiles and propellant charges are manually loaded into alternate chambers. The entire carrier rotates incrementally to successively align each chamber with the rotated breech. The rounds are rammed into the breech by an L-shaped rod that is geared to a stationary track fixed to the cab roof.

Projectiles and propellants are manually loaded into alternate chambers. Because of the height of the loading mechanism and the space required above and behind the cylinder to reload, the cylinder assembly must be lowered to be manually reloaded. The cylinder assembly must also be moved either laterally or rearward in order to avoid interferring with cannon recoil at lower cannon elevations.

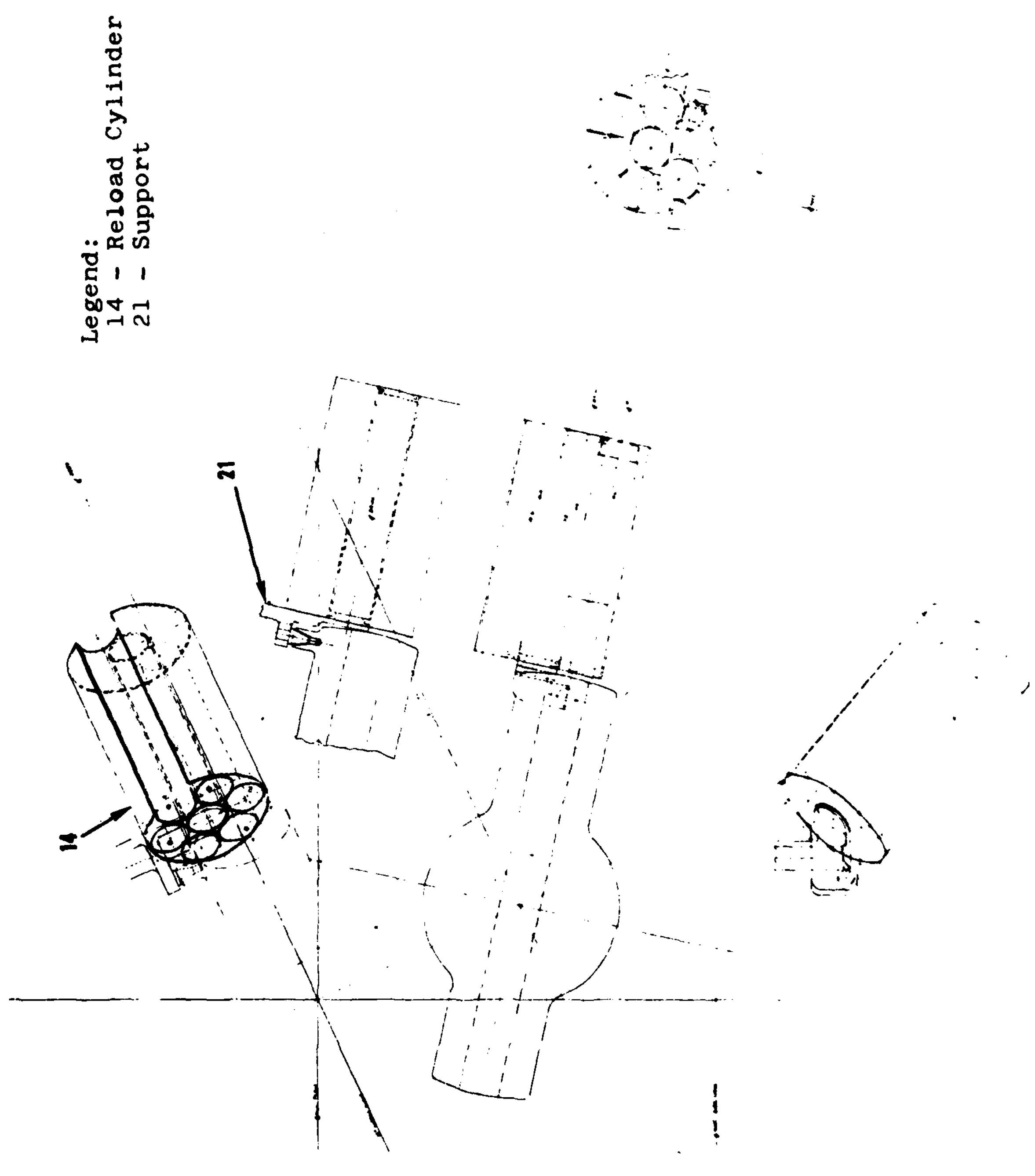


Figure 4-1. Three Round Rotating Cylinders

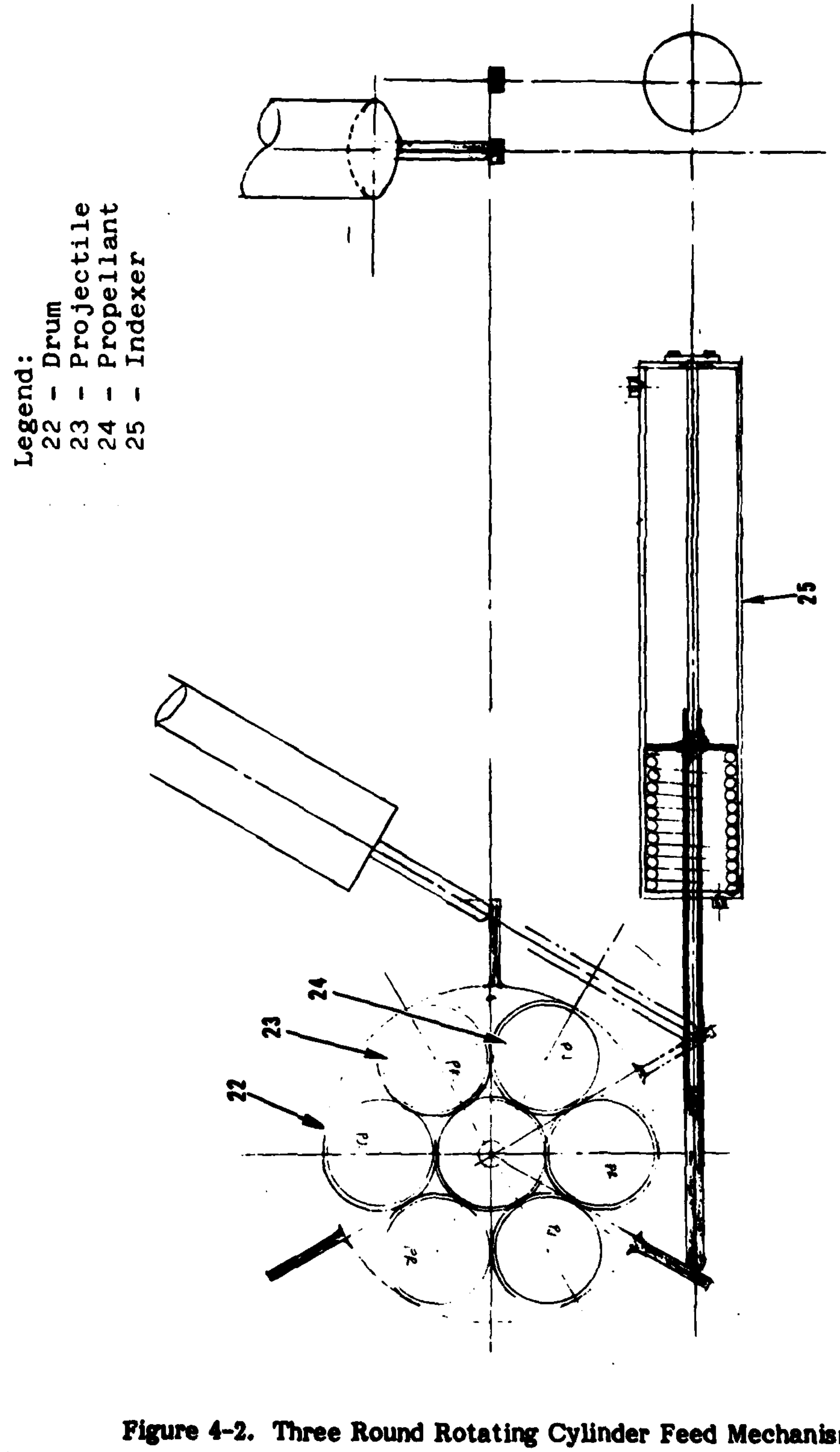


Figure 4-2. Three Round Rotating Cylinder Feed Mechanism

4.2.2 Single Chain Conveyor (Figure 4-3)

The single chain conveyor concept utilizes two continuous chain loops directly behind the rotated breech with one loop fore and the other aft. The chain loops are connected by evenly spaced rods that have L-shaped cradling tabs attached. The cradling tabs support the rounds from beneath and on one side. The entire chain conveyor is mounted on the cab roof to align with the axis of the rotating breech. The rounds are prevented from falling between the chains on the other side by two guide bands. The rounds are manually loaded on the cradling tabs, alternating projectiles and propellants. As the chain loops are rotated, the rounds are raised to the top of the loops where the guide bands lead to a ramming tray. The rounds fall between the chain loops and into the ramming tray, which is aligned with the rotated breech. The rounds are rammed into the breech by a zipper ram similar to that developed for the XM803 tank automatic loader. The zipper ram consists of two roller link chains that individually flex in one plane to facilitate storage, but became rigid when zipped together by driving them through two opposing sprockets.

4.2.3 Dual Chain Conveyor (Figure 4-4)

The Dual Chain Conveyor concept utilizes two sets of continuous chain loops, forming two conveyors, one on each side of the breech. On each side, two chain loops, one fore and one aft are routed up the side walls of the cab, along the roof to the center and then return via the same route. The chain loops are connected at evenly spaced intervals with rods that have cradling support tabs to carry the rounds. One conveyor transports projectiles, while the other transports propellants. Under each conveyor is a supporting surface to support the rounds vertically as they travel along the roof. Between the conveyors is a loading tray that receives a round from either conveyor and raises and tilts it to the loading position via a hydraulic cylinder and scissoring support. The projectile and propellant are raised separately in the loading tray and rammed via a zipper ram. The loading tray must also be moved rearward to avoid interferring with cannon recoil at lower cannon elevations.

4.2.4 Guided Ramp Conveyor (Figure 4-5)

The systems described thus far require manual loading of the projectiles and propellent canisters onto the loading mechanism. An additional mechanism could be devised to load each of these systems, but such a mechanism could also load the breech directly, eliminating the need for the system and reducing manpower requirements.

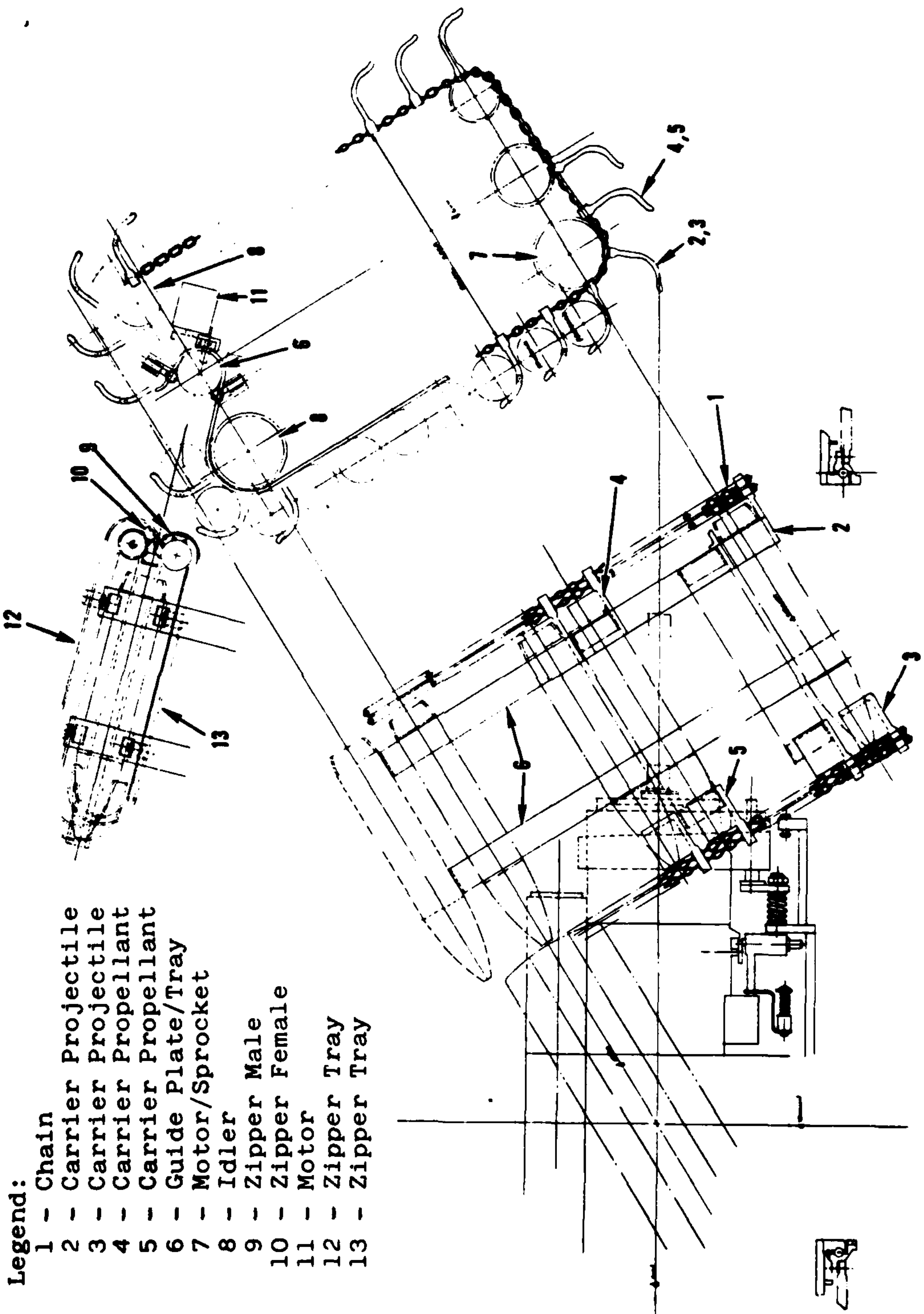


Figure 4-3. Single Chain Conveyor

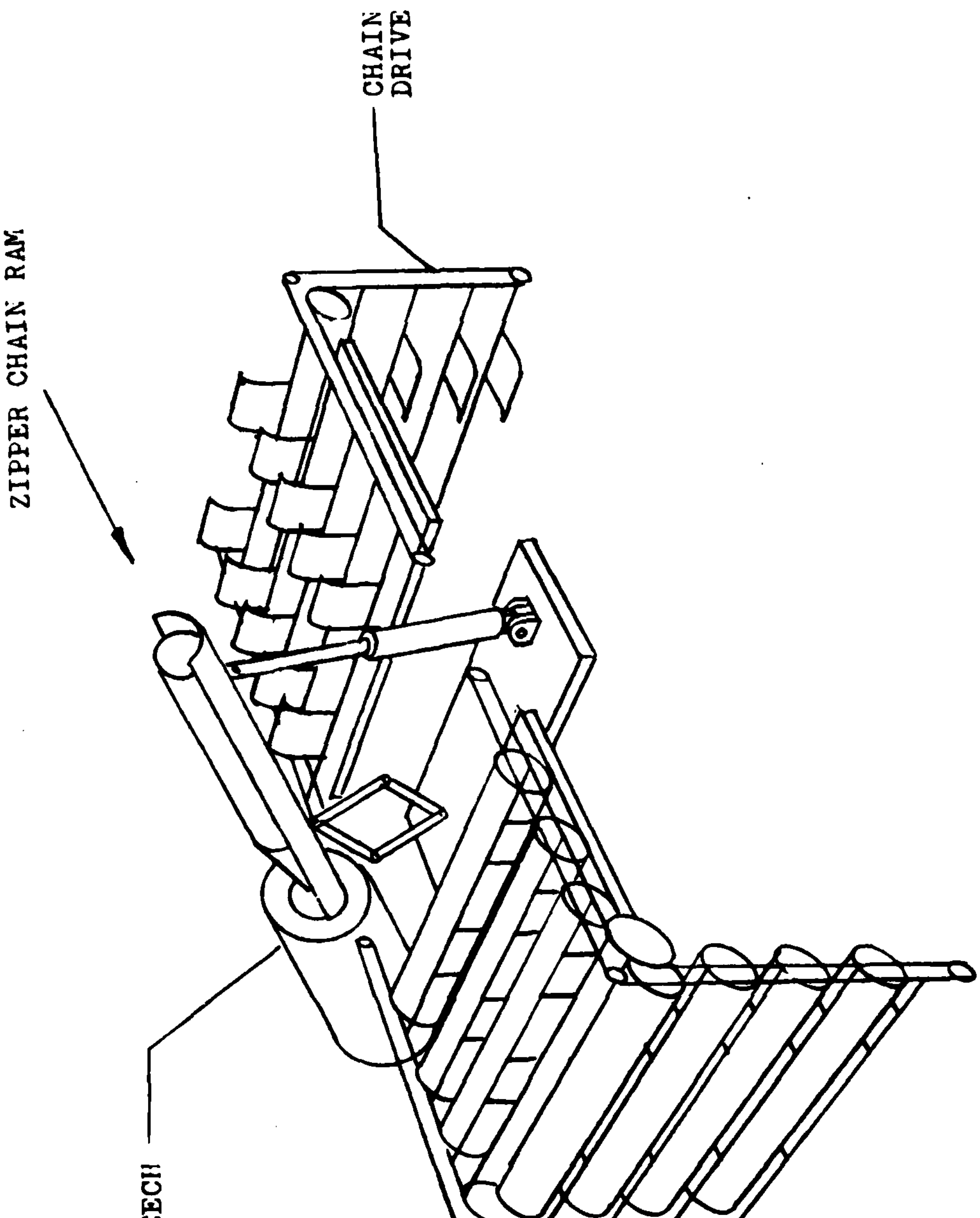


Figure 4-4 Dual Chain Conveyor

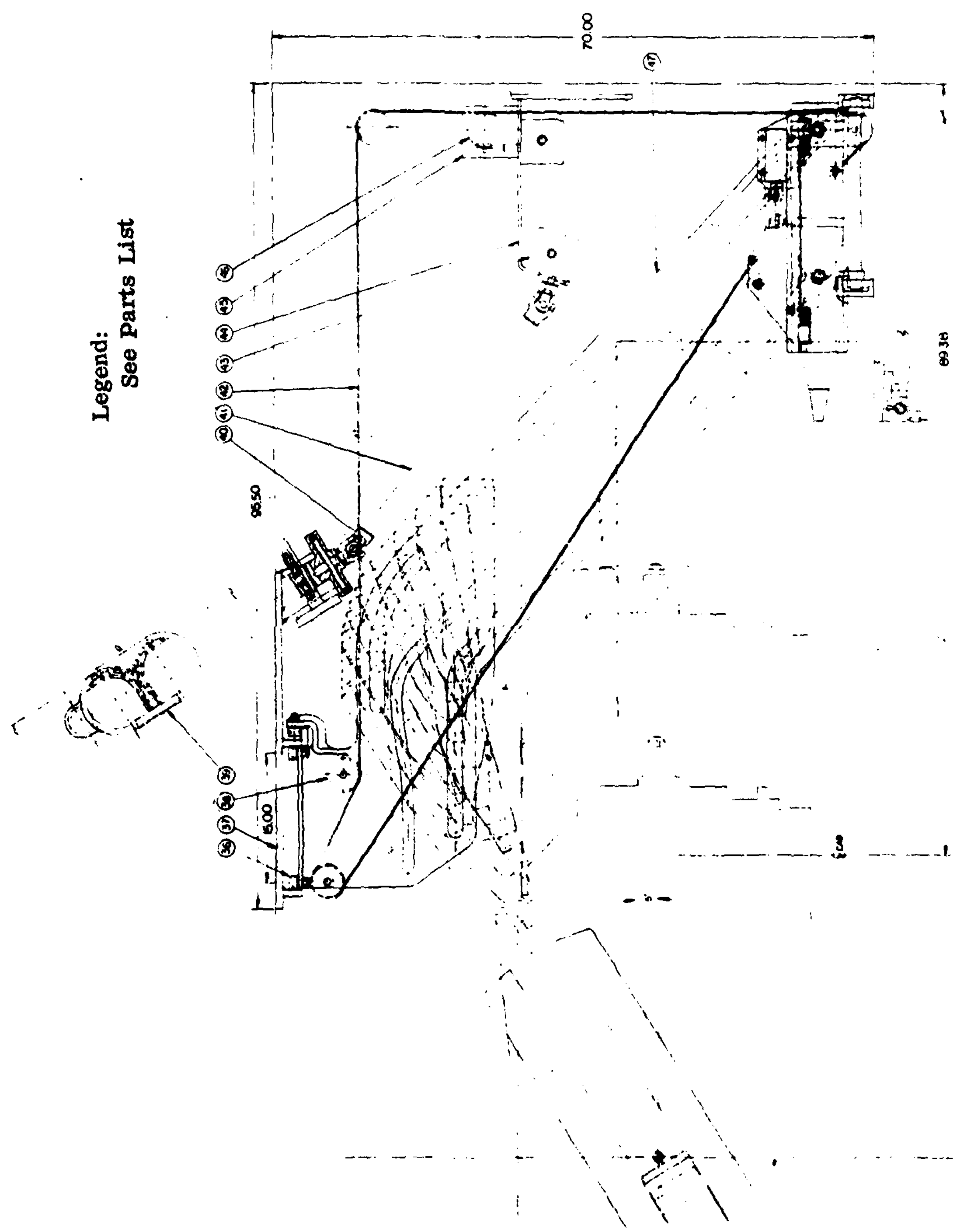


Figure 4-5. Guide Ramp Conveyor

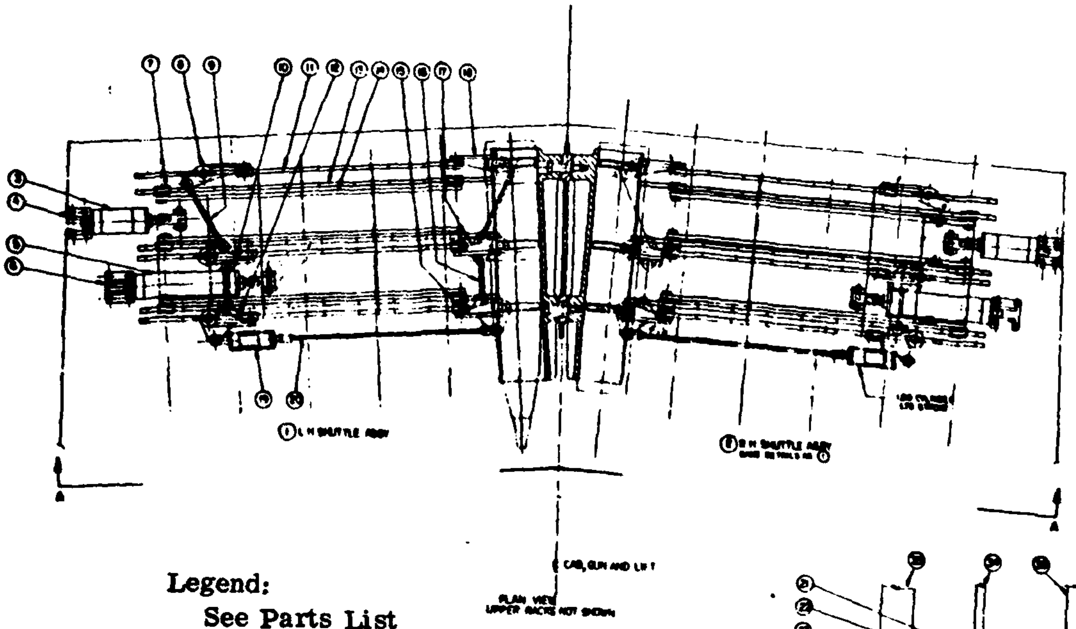
The following loading system consists of vertical gravity feed storage racks, lateral conveyors, an elevating and positioning conveyor and a ram. Projectiles are stowed in one side of the bustle, with propellants on the other. They are stacked in vertical columns, enabling different types of rounds to be stowed in different columns. The rounds are fed down the columns into lateral conveyors, which incrementally transfer them to the center of the bustle. Here a projectile and propellant are both loaded into a tray which is guided to the breech loading position. The tray is shifted laterally to align the projectile and then the propellant with the breech for ramming. After ramming, the tray returns to the bustle for reloading.

4.2.4.1 Lateral Conveyor (Figures 4-6 & 4-7)

A lateral conveyor is located on each side of the bustle; one is for propellants and the other for projectiles. Each lateral conveyor consists of three sets of cradling guides (Items 11 and 13) which support the rounds. The guides are positioned laterally across the floor of the bustle and have evenly spaced cylindrical depressions to support the rounds. One set of guides moves only vertically (Item 13) while another shuttling set (Item 11) moves both vertically and laterally. The vertical and lateral motions are controlled by lateral hydraulic cylinders and cammed ramps on the bottom of the guides. The vertical set of guides is normally in the raised position. To transfer rounds, the vertical guides lower the rounds to the shuttling guides which then raise and laterally transfer the rounds one position; the vertical guides rise to support the rounds while the other lowers and returns. Spring loaded levers (Item 32) that sense the presence of rounds are mounted on the shuttling guide at each round position. If a round is present, the lever is depressed; if not, the lever springs to a raised position to engage a latch release on the bottom of the stowage feed racks. These levers also cushion the fall of the rounds, which are fed from above by stowage/feed racks.

4.2.4.2 Stowage/Feed Rack Description (Figures 4-8 & 4-9)

The stowage/feed racks consist of three transverse rows of vertical brackets attached to the cab roof (Items 33, 34, and 35). The rounds point forward and are supported on one side by ammunition nestling/sensing levers (Item 23) on the vertical brackets and supported laterally on the other side by the adjacent vertical brackets. The nestling/sensing levers are attached to a rod that passes through the vertical brackets and are spring loaded so that the nestling portion of the lever rotates vertically, allowing a round to drop.



Legend:
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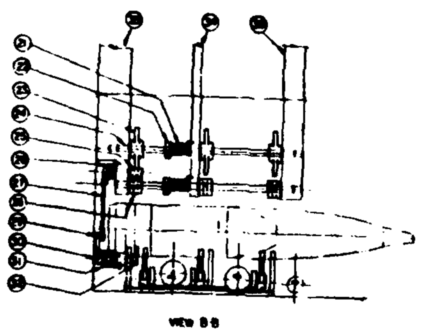


Figure 4-6. Guide Ramp Conveyor - Lateral Conveyor

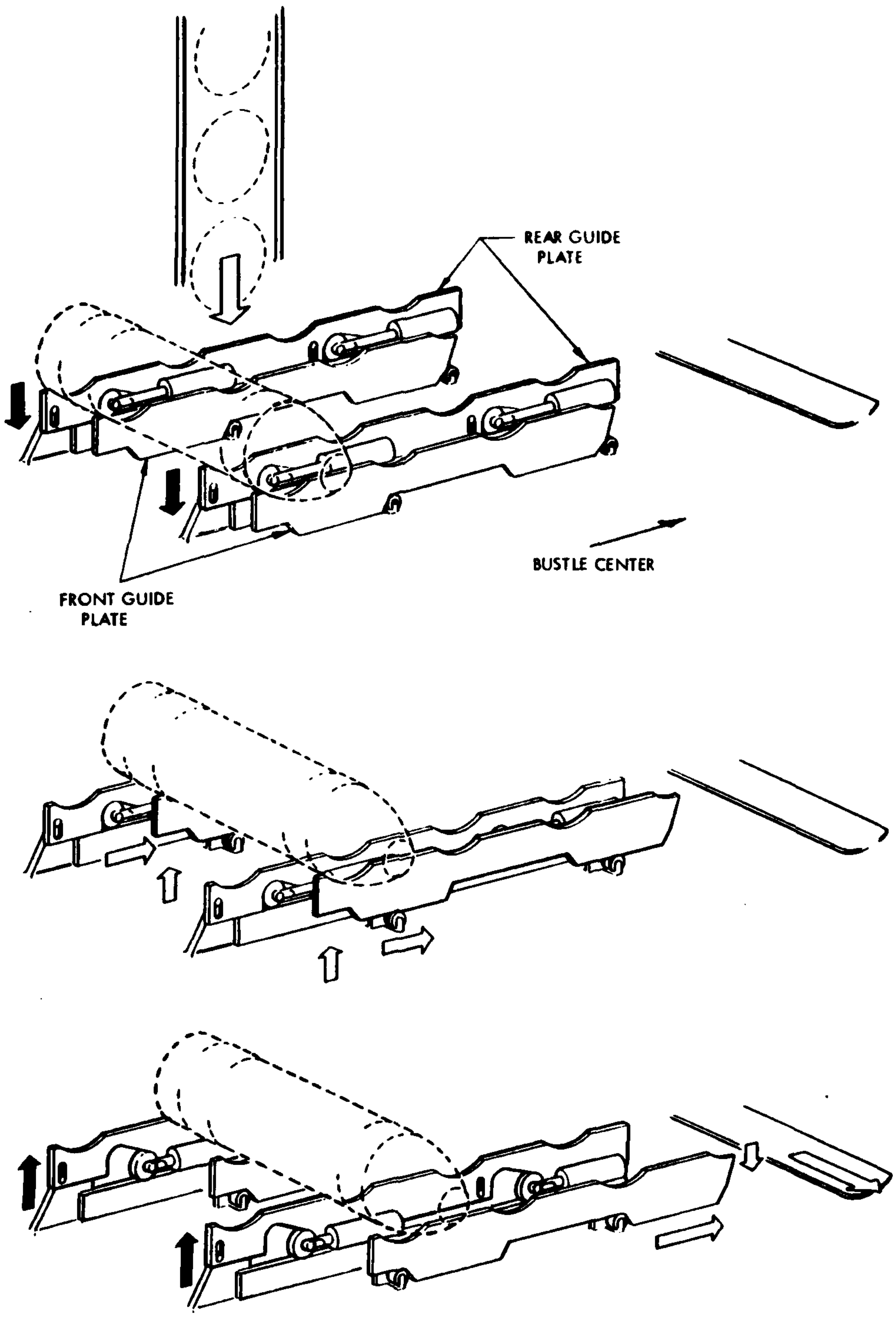


Figure 4-7. Cammed Guide Plate

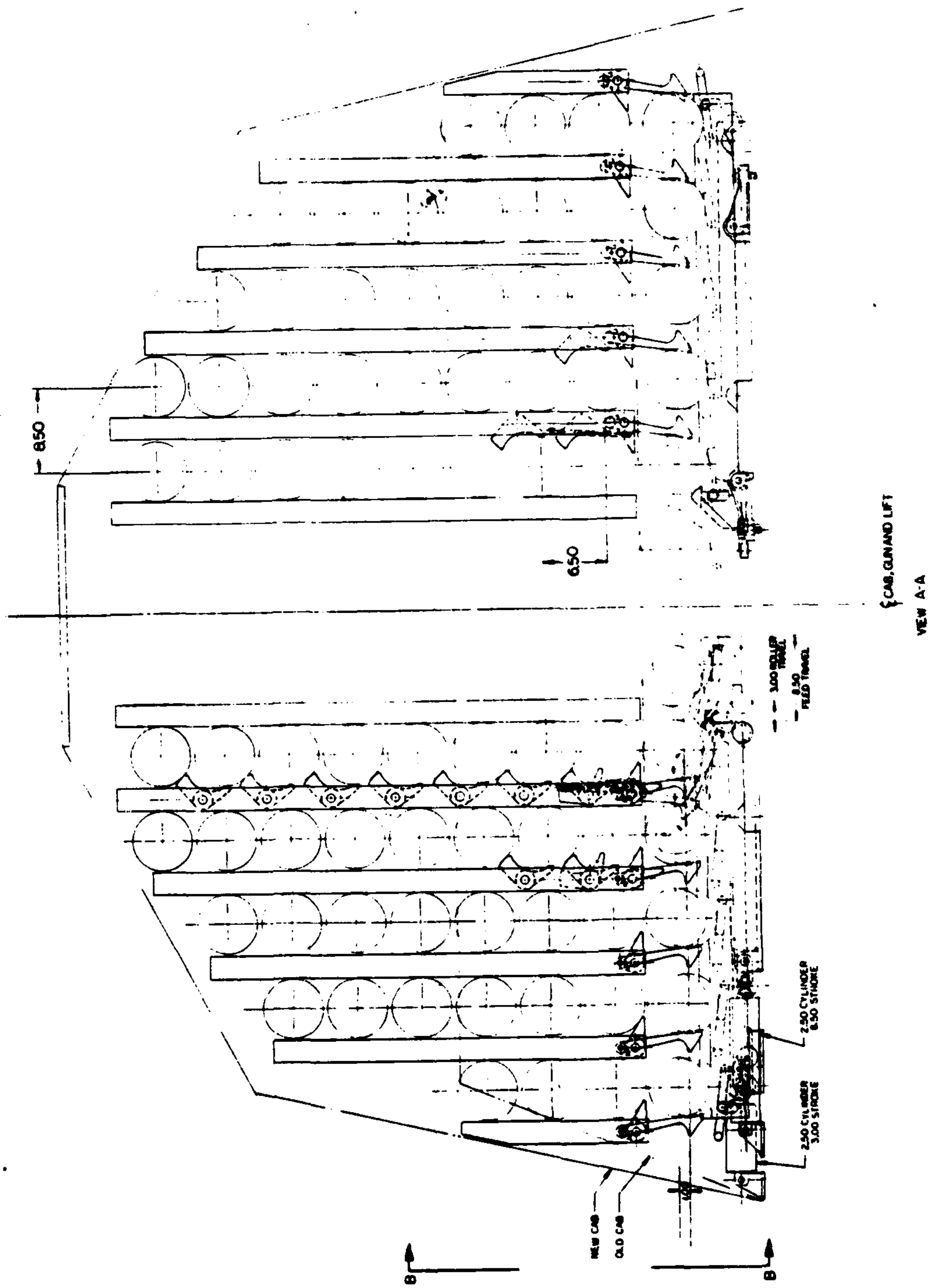


Figure 4-8. Guide Ramp Conveyor - Bustle Stowage

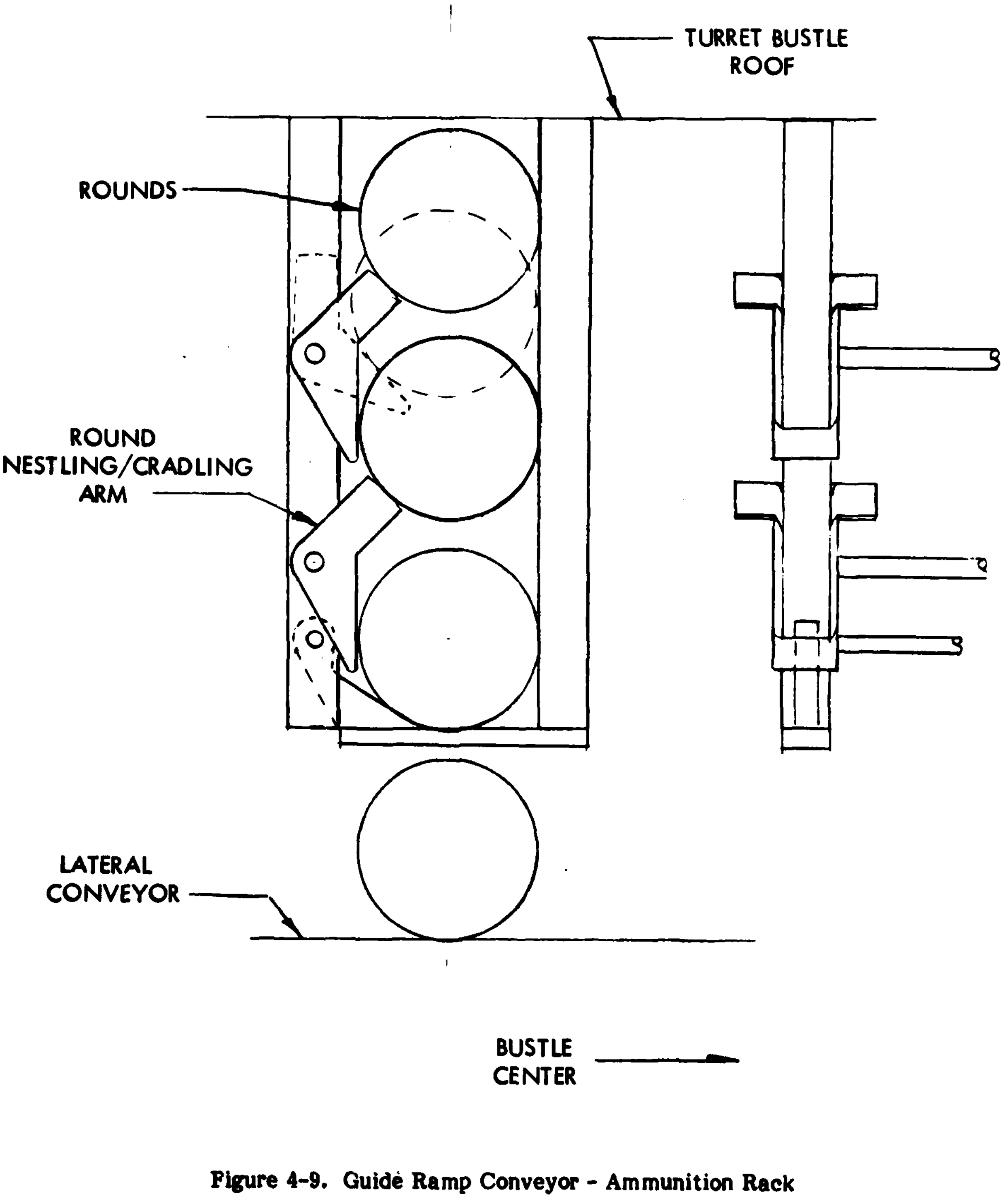


Figure 4-9. Guide Ramp Conveyor - Ammunition Rack

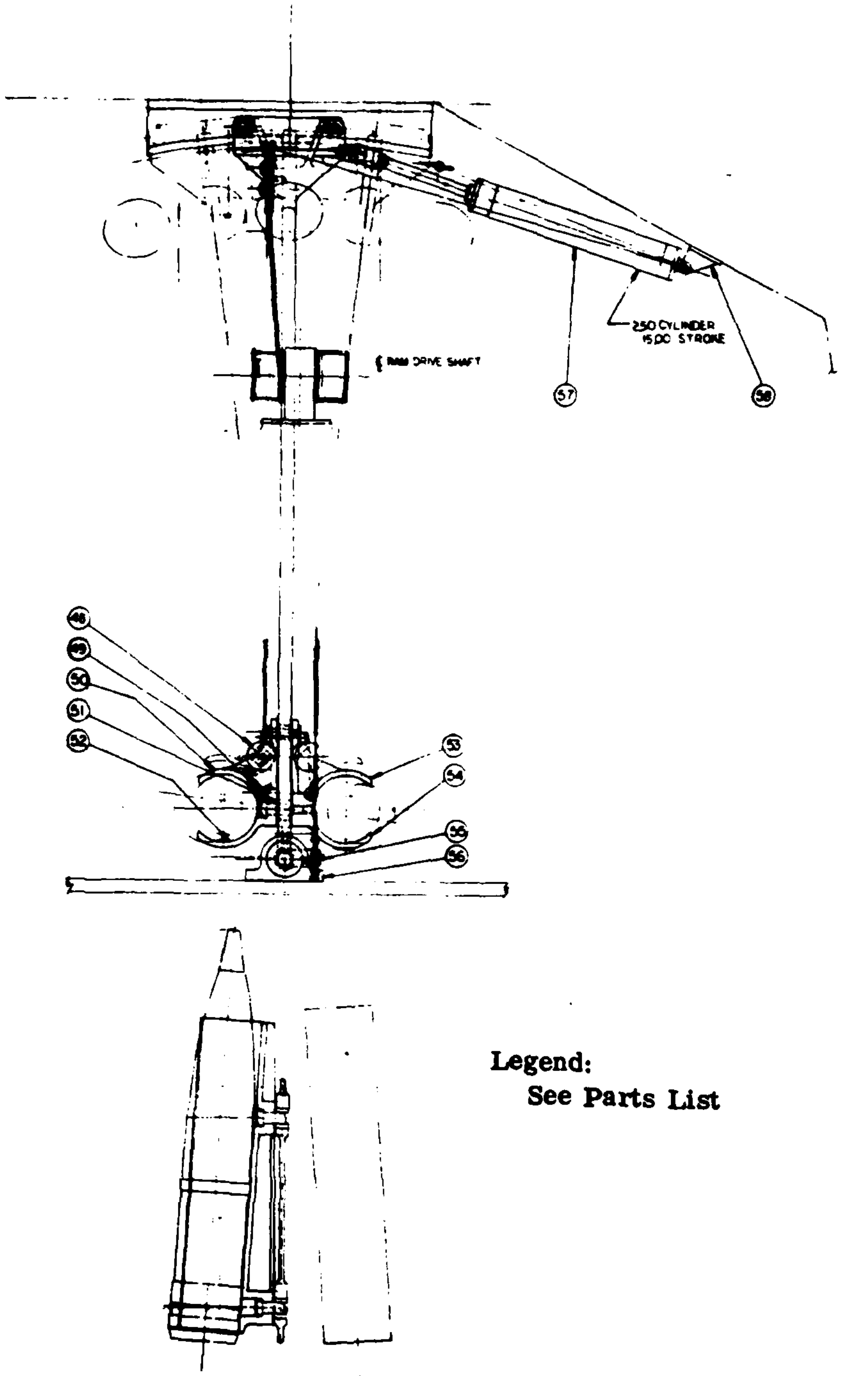
The bottom round is held by a spring loaded pivoting support lever (Item 28) that is latched. The release of the bottom round is controlled by the position of load sensing levers (Item 32) on the lateral conveyor or by an overriding manual latch. As the lateral conveyor returns from advancing the rounds, it releases the latch on the bottom round support. As the lower round drops to the lateral conveyor, the support lever rotates downward, which in turn (Item 27) prevents the round above from dropping. After the lower round drops past the support lever, the lever springs back and is latched, which simultaneously releases the nestling lever of the round above, allowing it to drop. This in turn releases the nestling/sensing arm of the next higher round, allowing it to drop. This action continues up the storage column.

4.2.4.3 Bustle to Breech Conveyor (Figure 4-10)

The final position of the lateral conveyor places the round in a tray (Item 52) which carries it from the bustle to the breech. The projectile is placed in one tray and the propellant in another. The trays are connected by roller-followers (Item 51) which are in guide tracks (Item 47) to the breech. Both the projectile and propellant are raised to the breech simultaneously. The guide tracks are hinged at the bottom (Item 55) of the bustle to allow the guide tracks and conveyor trays to be shuttled laterally to align the projectile and propellant with the breech for ramming. Once both the projectile and propellant charge have been rammed, the trays return to the bustle for reloading.

4.2.4.4 Zipper Ram (Figure 4-11)

The zipper ram is a ram pushed by two chains which lock together when driven through two opposing sprockets. The chains are flexible in one plane prior to being driven through the sprockets; this eliminates the need for storage space directly behind the rammer drive. The chains lock together and become rigid when driven through the sprockets, transmitting sufficient ramming force to the round. The length of the ram can also be controlled to enable the projectile to be rammed far enough to leave room for the propellant.



Legend:
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Figure 4 - 10. Guide Ramp Conveyor - Elevating Conveyor

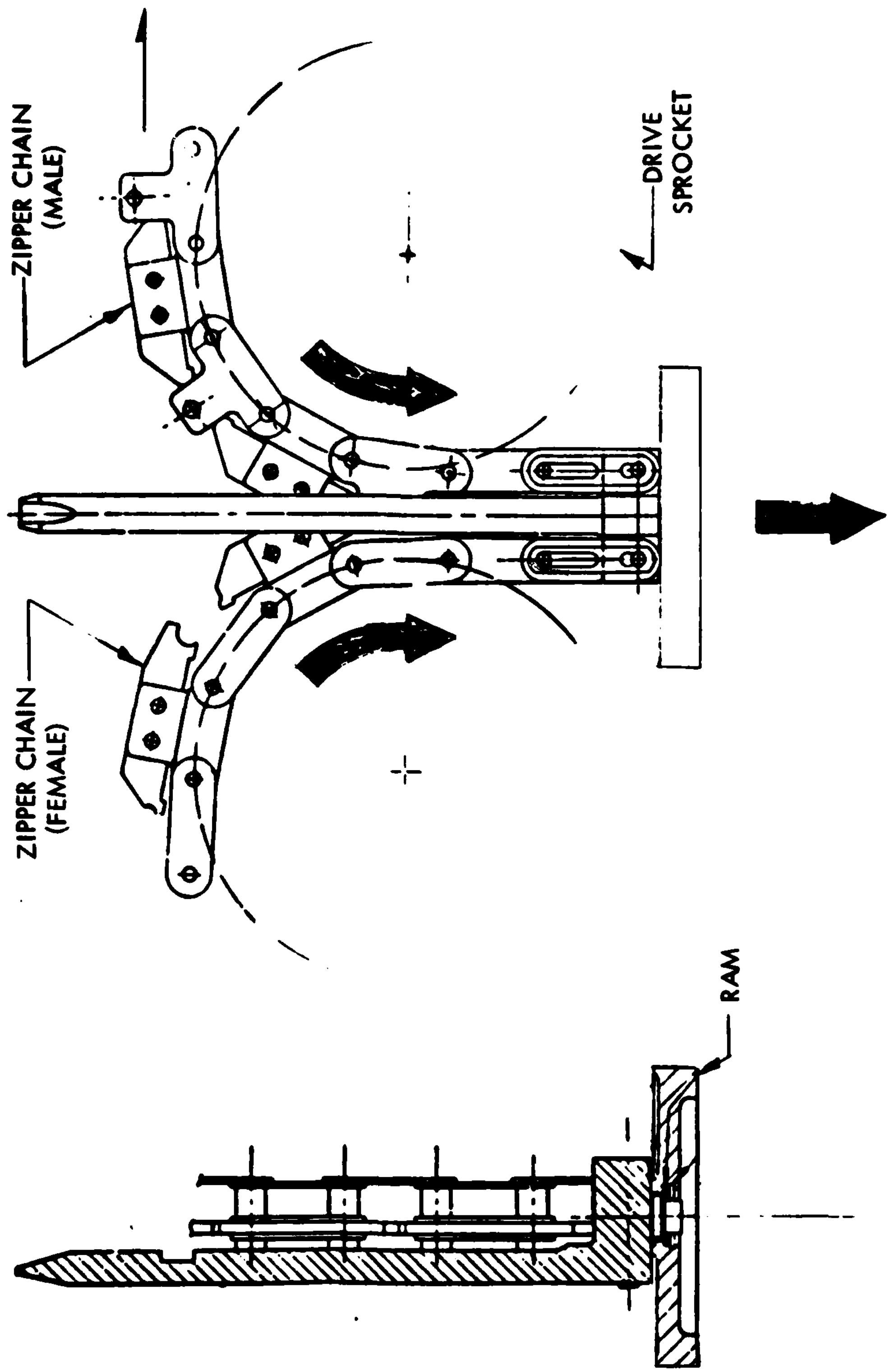


Figure 4-11 Zipper Chain Rammer

4.3 SUBSYSTEM CONCEPTS

This section describes alternate automated loader subsystems that were considered in developing the loader concepts described in section 4.2.

4.3.1 Rotating Guide Plates (Figure 4-12)

This system utilizes sets of guide plates which rotate about a lateral axis and are syncronized so that when one is vertical, the other is horizontal. The guide plates are cylindrically notched at equal intervals to positively capture the rounds. One guide plate is mounted on a lateral guide shaft to permit lateral motion, the other does not move laterally. Rounds are supported on straight guide rails located between the guide plates.

To transfer the rounds, the stationary guide plate is rotated down to a horizontal position beneath the rounds while the other guide plate simultaneously rotates up to a vertical position, so that its "fingers" are between the rounds. This guide plate is then transferred laterally, indexing the rounds one position along the guide rails. It is then rotated horizontally while simultaneously rotating the stationary guide plate vertically to capture the rounds. The indexing guide plate then returns beneath the rounds.

4.3.2 Twin Lead Screws with Conveyor Tray (Figure 4-13)

This concept utilizes two lateral lead screws which drive a transfer tray across the bottom of the bustle. The tray is stopped beneath a column of stowed rounds, a round is dropped into the tray, and is then transferred to the center of the bustle to deposit the round in a bustle-to-breech conveyor.

4.3.3 Twin Lead Screws (Figure 4-14)

This concept uses lateral twin lead screws with a pitch slightly greater than the diameter of a round. The rounds are fed into the screws from a column of stowed rounds. As the screws are rotated simultaneously, the round advances toward the center of the bustle.

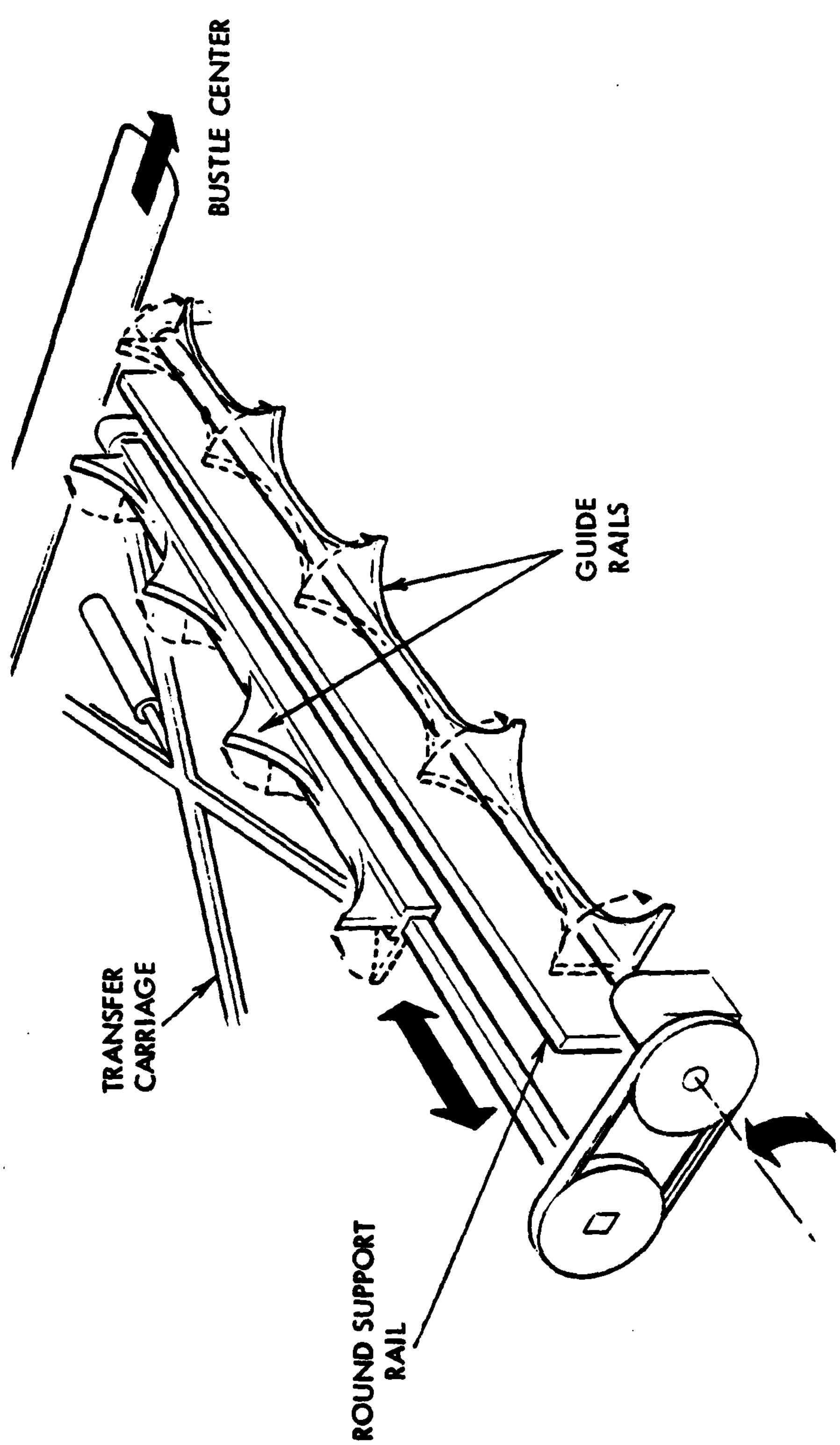


Figure 4-12. Rotating Guide Plates

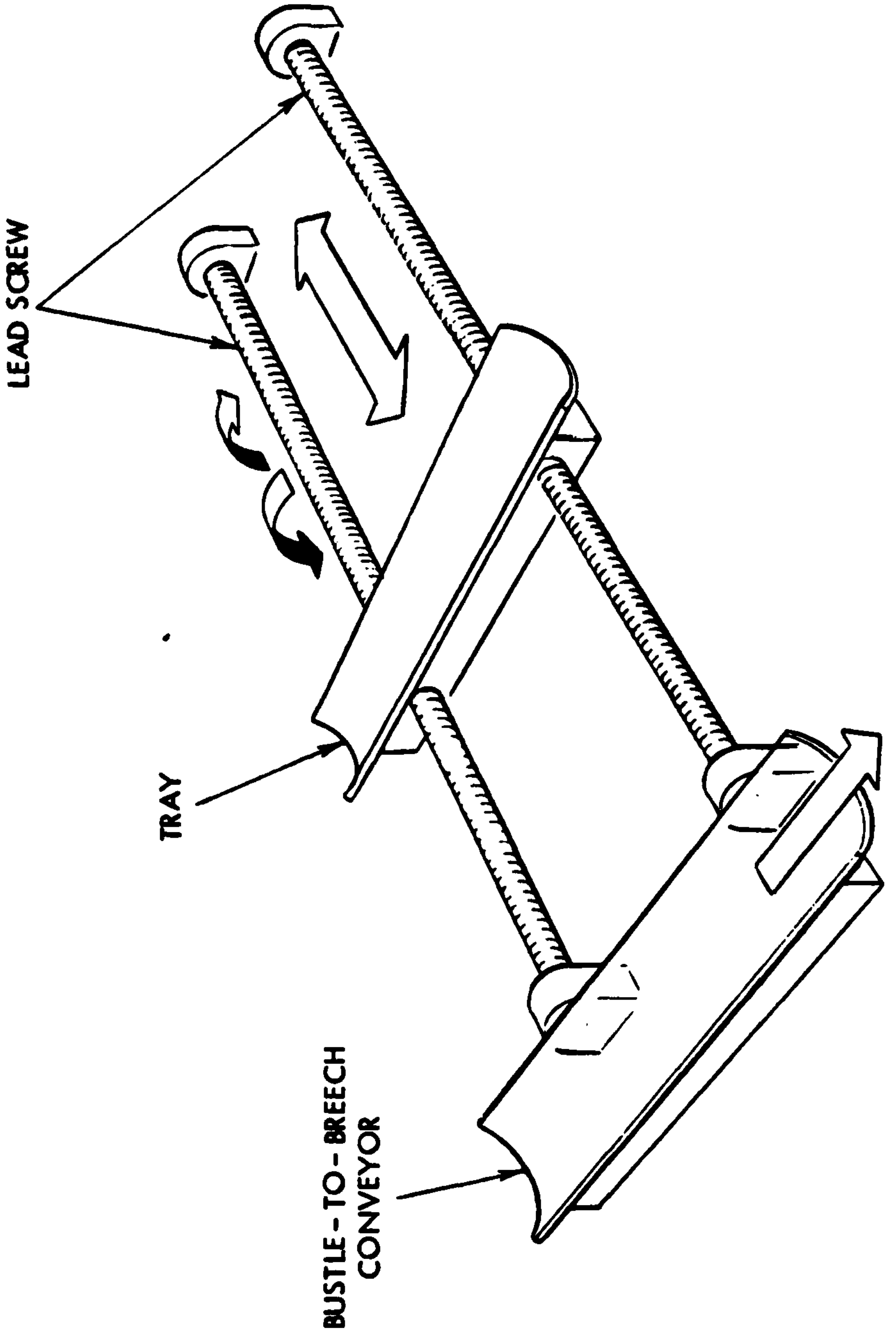


Figure 4-13. Twin Lead Screws with Conveyor Tray

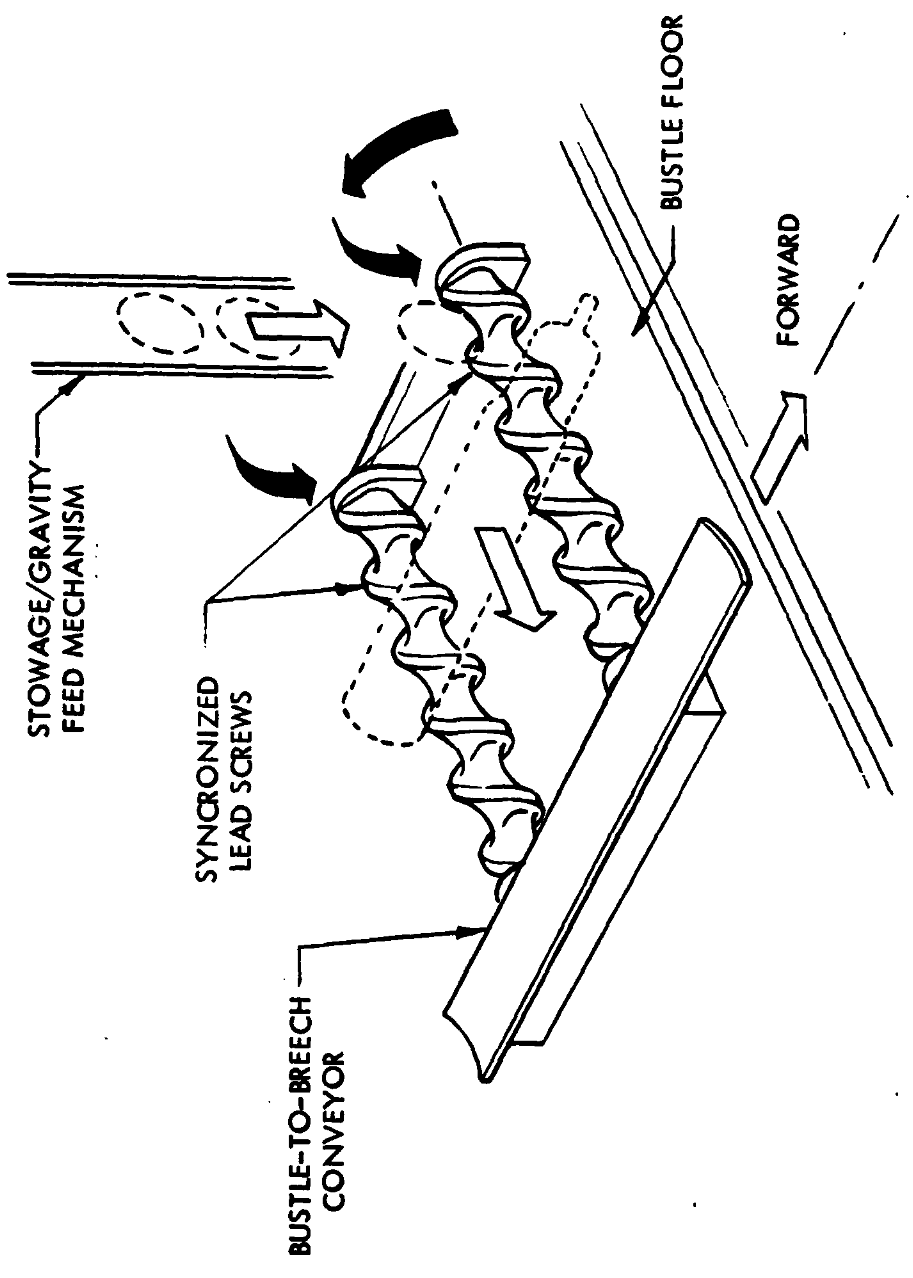


Figure 4-14. Twin Lead Screw Conveyor

4.3.4 Opposed Crank Guide Plates (Figure 4-15)

This concept utilizes straight lateral support rails and sets of guide plates with evenly spaced vertical fingers that guide the rounds toward the center of the bustle. The guide plates are connected to each other by opposed cranks that are supported by bearings through the fixed guide rails. As the cranks are turned, the rounds advance toward the center of the bustle.

4.3.5 Chain Conveyor with Locating Fingers (Figure 4-16)

This lateral conveyor concept consists of continuous chain loops which travel laterally along the bustle floor. L-shaped hinged fingers are attached to the chain to guide the rounds along guide rails toward the center of the bustle, along the top of the chain loop. The short leg of the L-shaped finger is guided by the support rails such that the long leg is vertical. On the bottom return loop the finger is released so that the short side is vertical, requiring less clearance.

4.3.6 Sliding Guide Tray (Figure 4-17)

This concept utilizes straight sliding guides to transfer a loading tray from the center of the bustle to a loading position. The guides must not interfere with the cannon recoil. Some methods of avoiding this interference are to telescope the guides from the bustle so they are retracted during firing, or to straddle the guides on each side of the cannon so the cannon recoils between the guides. For this concept, the loading tray must also be rotated to align with the breech, since the orientation of the rounds in the bustle and the axis of the breech differ.

4.3.7 Scissored Tray

For this concept, the tray is conveyed from the bustle to the breech by scissoring links beneath the tray. The scissors can be designed so that the tray is rotated to align with the rotated breech for ramming. This enables the round to be conveyed to the breech and rotated to align with the breech in a single motion and with a single power source.

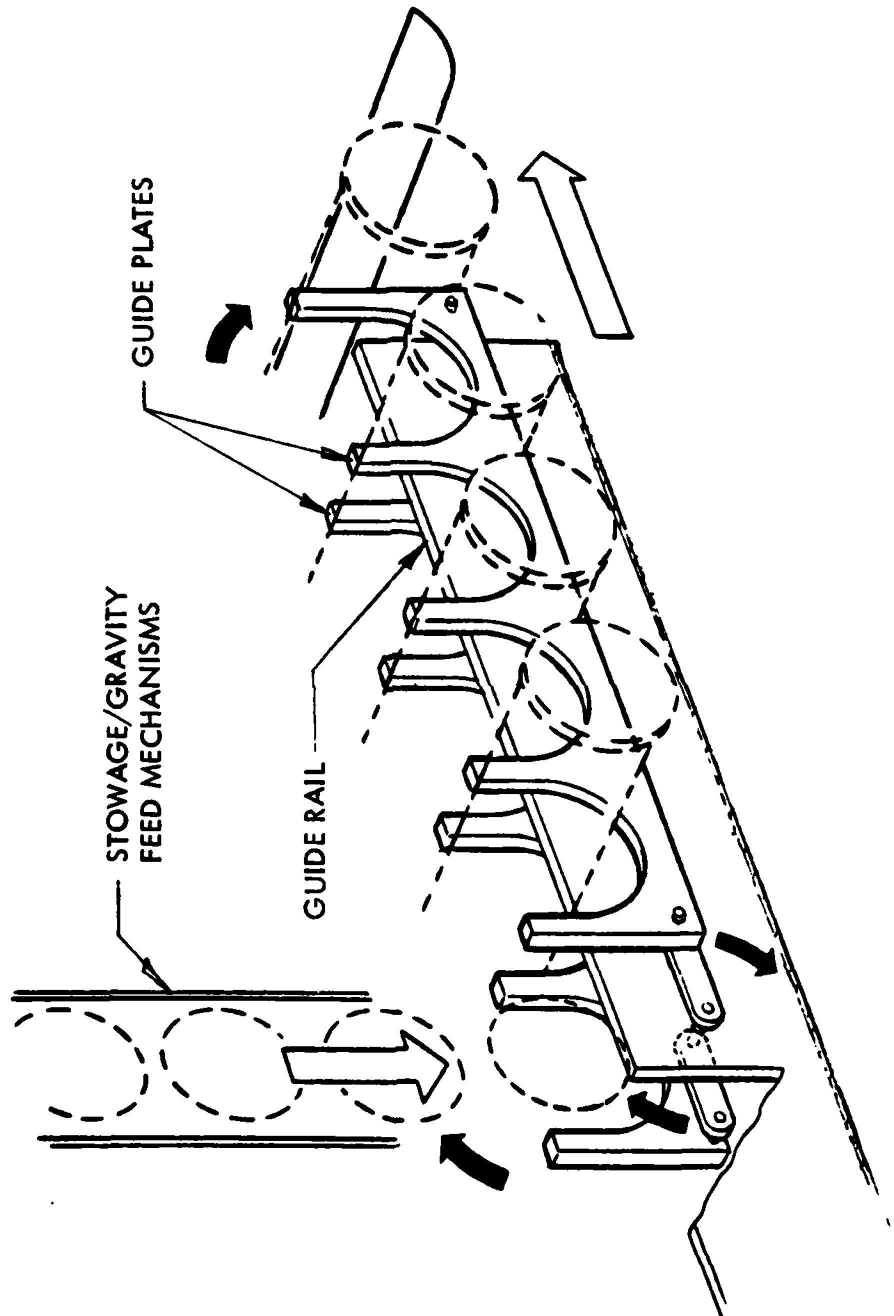


Figure 4-15. Opposed Crank Conveyor

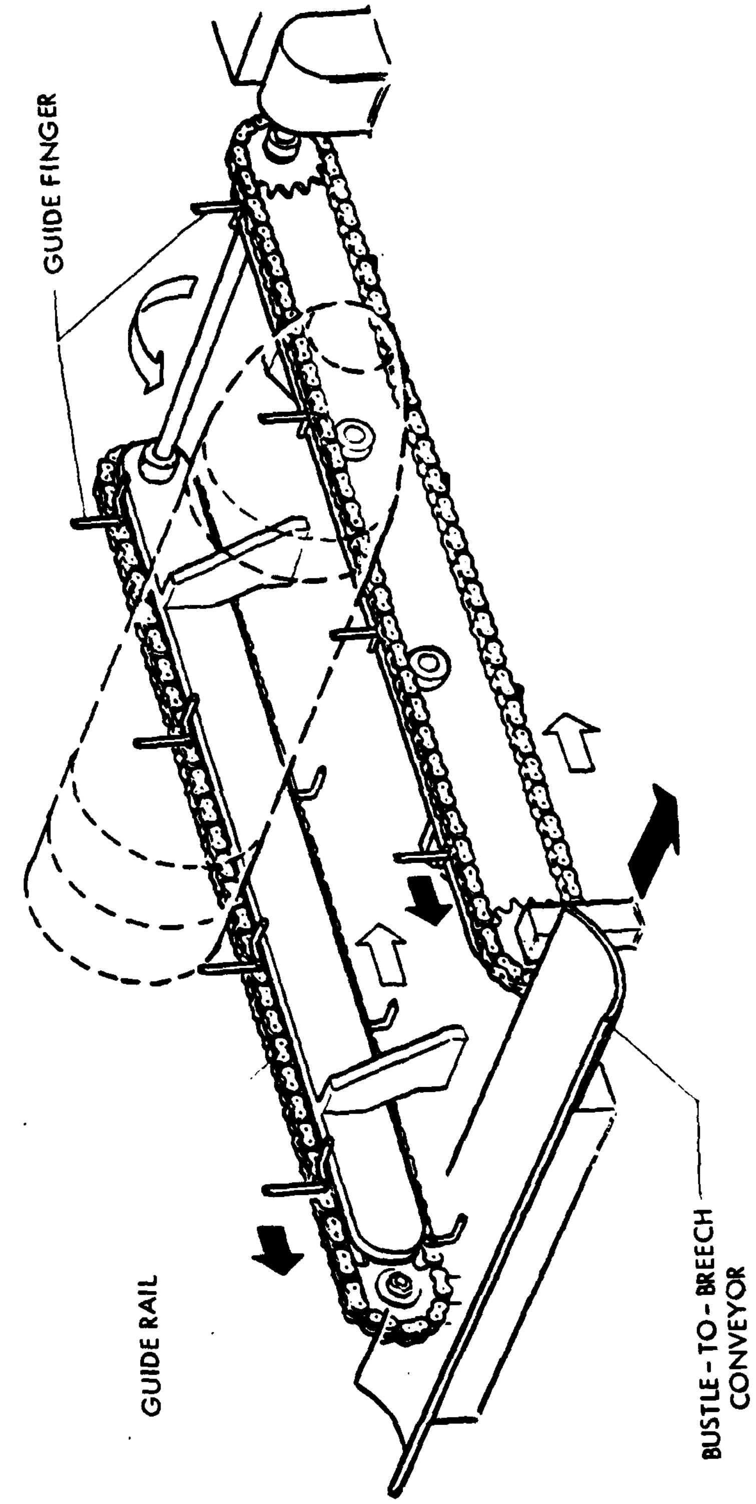


Figure 4-16. Chain Loop Conveyor

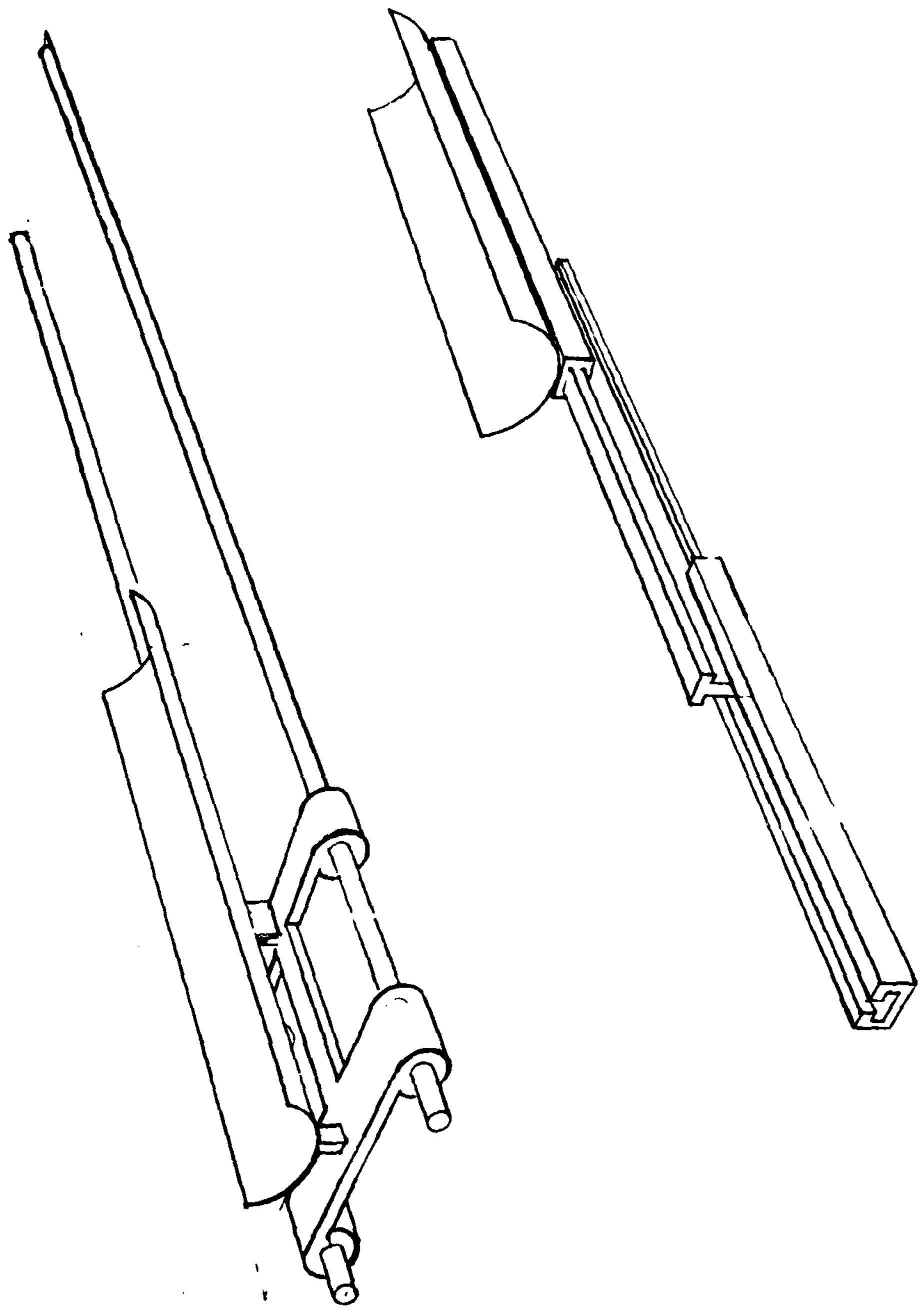


Figure 4-17. Sliding Guide Trays

Rod Rammer (Figure 4-18)

This rammer consists of a solid straight rod with a gear rack along its length. It is driven by a gear which also travels in a stationary gear rack. The gear is driven linearly by a hydraulic cylinder. The rammer can engage the round with the finger at the rear of the rod, which would ram the round to the mouth of the breech. In a subsequent motion, the rammer could be shifted to continue ramming a projectile further into the breech with the front of the ram rod in order to leave space for the propellant.

Chain Rammer (Figure 4-19)

The chain rammer consists of a chain loop around two sprockets. The sprockets are both mounted on a carrier, which is restricted by a linear guide. The top of the chain loop is fixed with respect to the guide at one sprocket. A ramming finger extends from the bottom of the chain loop at the other sprocket. The ram can be powered by either a hydraulic cylinder moving the carrier/sprocket assembly or with a motor rotating a sprocket. As the carrier moves along its guide the ramming finger travels twice the distance as the carrier.

4.4 SYSTEM EVALUATION

The four systems to be evaluated are the Rotating Cylinder, Single Chain Conveyor, Dual Chain Conveyor and In-Bustle Conveyor Concepts previously described.

The following are the criteria used in evaluating these concepts, arranged roughly in order of decending importance: 1) Crew Safety - the degree that the presence of the automatic loader increases the risk of crew injury; 2) Crew Survivability - the degree to which the crew is expected to survive should the vehicle be penetrated by enemy fire; 3) Reliability, Availability and Maintainability -the degree of confidence that the mechanism will function properly for an extended period of time without breakdown and the frequency and ease of periodic preventative maintenance; 4) Rate of Fire - The speed that a three round volley can be fired and the rate of continual firing; 5) Crew Task Reduction - the extent to which the loader either eliminates or reduces the complexity of required crew tasks; 6) Manual Back-up - the relative ease that the howitzer can be manually loaded in the event of a failure in the loading mechanism; 7) Space Required - the amount of additional space and the instrusion into current cab space by the loading mechanism; 8) Logistics - the frequency and ease of rearming

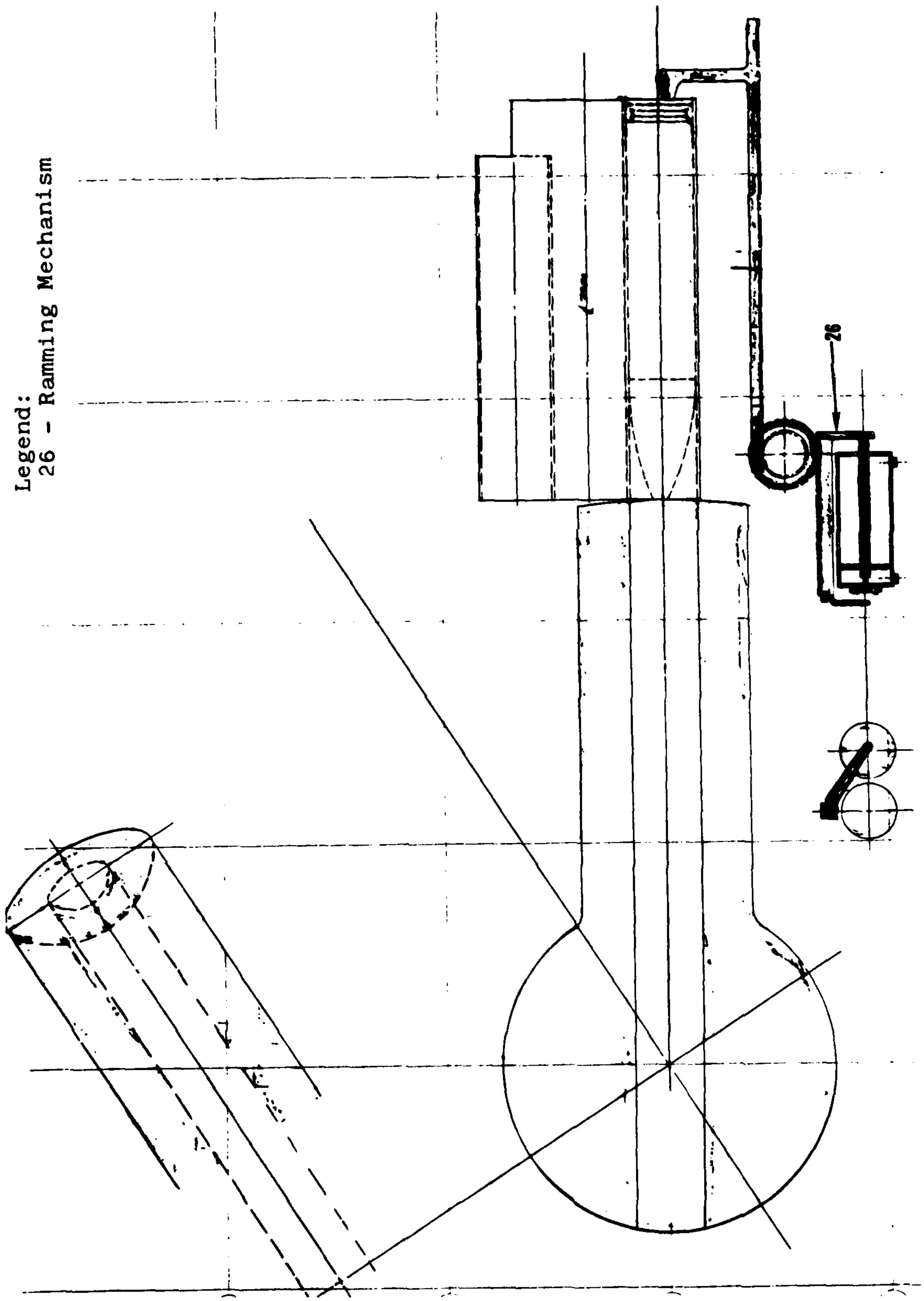


Figure 4-18. Powered Rod Rammer

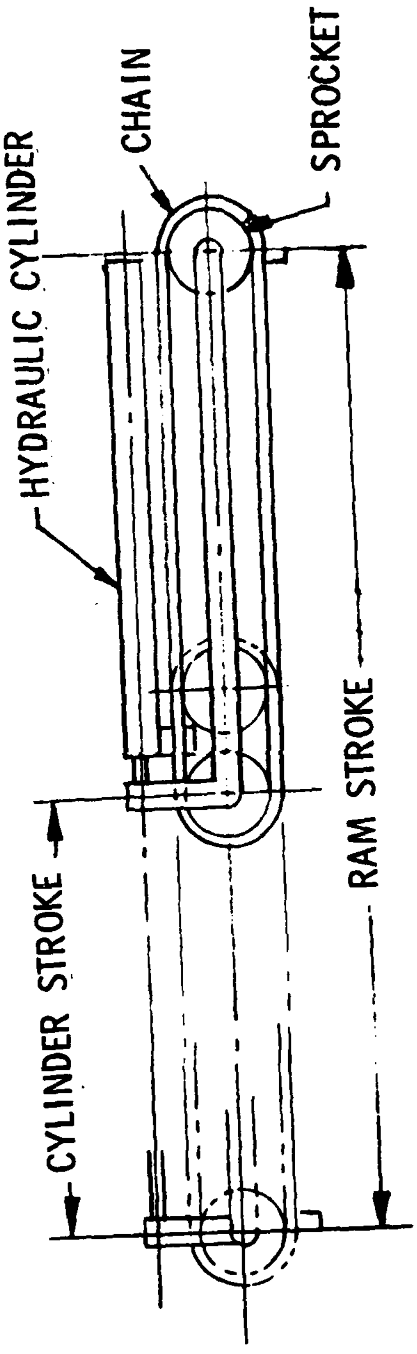


Figure 4-19. Chain Rammer

the vehicle; 9) Number of Rounds - the number of ready rounds and the total number of rounds stowed in the vehicle; 10) Power - the amount of power required to operate the loader; 11) Weight - the net amount of weight change caused by the presence of the loader: 12) Cost.

The following relative evaluations of the loader concepts are summarized in table 4-1. The concepts were compared among themselves and not against the current loading procedure because the relative degrees of merit were not known for the current procedure.

Table 4-1. Relative Evaluation of Loading System Concepts

	System			
Criteria	Rotating Cylinder	Single Chain Conveyor	Dual Chain Conveyor	Guided Ramp Conveyor
Crew Safety	2	4	3	1
Survivability	1	1	1	2
R.A.M.	1	3	4	2
Crew Task Reduction	4	3	2	1
Manual Back-Up	2	2	2	1
Rate of Fire	2	4	3	1
No. of Ready Rounds	2	2	2	1
Power Required	1	3	4	2
Logistic Support	2	2	2	1
Crew Space Required	2	3	4	1
Added Space Req'd	1	2	4	3

NOTE: 1 = Most Favorable
4 = Least Favorable

4.4.1 Crew Safety

The Single and Dual-Chain conveyors are both relatively unsafe because they intrude into the crew compartment, exposing the crew to many moving parts. The Single Chain concept also restricts the movement of the crew from one side of the cab to the other, increasing the difficulty of entering/exiting and in performing crew functions. In the Dual Chain concept, the routing of conveyors along the walls not only limit crew operating space but also restrict access to instruments, controls and supplies on the walls. The rotating cylinder concept is relatively safer since it is only in the crew space when it is lowered for re-loading. For the guided ramp Conveyor concept, no portion of the conveyor enters the crew compartment and the rounds are securely held at all times, therefore this concept is relatively the safest.

4.4.2 Survivability

The greatest threat to crew survivability is the detonation of a round within the crew compartment. The Single and Dual chain conveyors have the greatest number of rounds in the crew compartment at one time and the least positive method of securing the round when loaded on the conveyor. The Rotating Cylinder has fewer rounds in the crew compartment and keeps them well secured. The guided ramp conveyor only exposes one well secured round to the crew compartment at one time.

The Rotating Cylinder and Single and Dual Chain concepts offer the greatest potential for isolating rounds from penetrating fire. Since in all the cases the rounds are manually unstowed, each round can be isolated and armored as much as desired. For the guided ramp conveyor concept, rounds in the outside rows and columns can be made non-ready and individually isolated. However, for the stowage/gravity feed racks, the protection is limited to isolating one column of rounds from another.

4.4.3 Reliability, Availability & Maintainability

The evaluation of the reliability, availability of the concepts is preliminary at this stage of development, since the concepts are not defined in detail.

The rotating cylinder concept appears to be the least complex and therefore the most reliable and easiest to maintain. It has redundant components to the extent that the six chambers serve the same purpose. The Single and Dual Chain conveyor concepts are somewhat

more complex and probably somewhat less reliable than the Rotating Cylinder. The most probable failures would result from fatigue or jamming of the chains. They are both redundant in that there are multiple round carrying brackets on the chain, and two conveyors available in the case of the Dual Chain concept. The guided ramp conveyor concept appears to be more complex because of the number of moving parts. Potential failures could occur due to broken springs or rounds jamming in the gravity feed system. We believe, however, that these potential problems can be avoided through careful design. This concept also has the most redundancies in that each gravity feed column can operate independently and there are two lateral feed conveyors.

For all concepts, periodic maintenance would consist of visual inspection and lubrication.

4.4.4 Rate-of-Fire

The sequence and estimated times required to fire a three round volley are shown in tables 4-2 through 4-5. It is believed that the estimated times are conservative and that the actual times would be somewhat less. For sustained firing, the limiting factor is how quickly the projectile can be manually fuzed and the projectile charge manually zoned.

4.4.5 Crew Task Reduction

For the Rotating Cylinder, Single and Dual Chain Conveyor concepts, there is no real reduction in crew tasks. The projectiles must still be manually unstowed, fuzed and placed in the loader. The propellants must also be manually unstowed, zoned and placed in the loader. For the Guided Ramp Conveyor concept, the projectiles and propellants are fuzed and zoned while stowed and do not require manual unstowing or loading.

4.4.6 Manual Back-Up

All systems provide a manual-back-up should the loader fail. At this point it is unclear whether any concept is superior in this respect. The Rotating Cylinder, Single and Dual Chain Conveyor concepts all utilize the same stowage system as is currently used. For the Guided Ramp concept, the rounds are passively fed by gravity to the bottom of the bustle. This feed system will continue to be operational unless there is extensive damage to the bustle. The difficulty of manually removing the rounds from the bottom row of the bustle is unknown. If the rounds are easy to remove, this concept would provide better manual back-up, since the

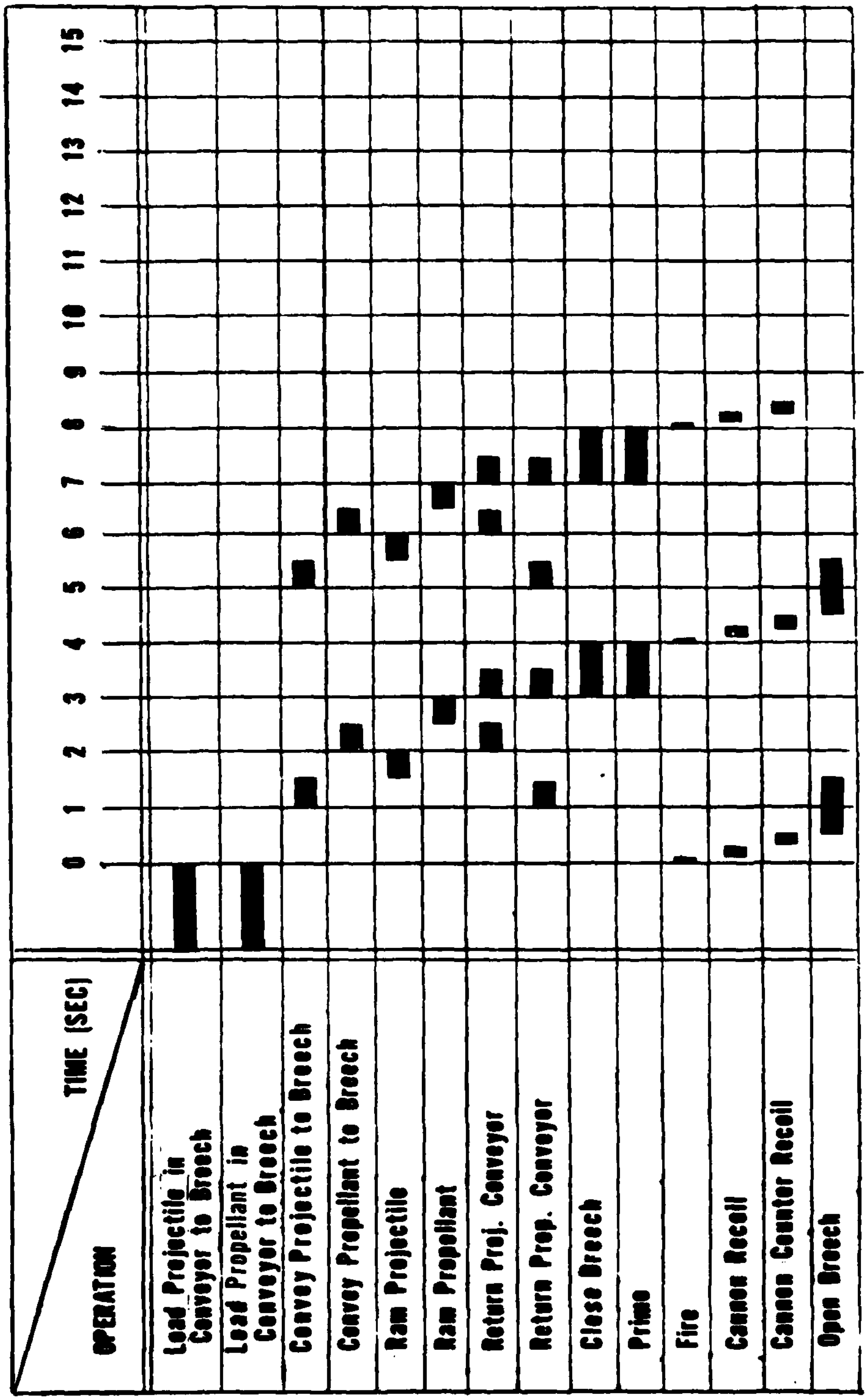


Table 4-2 Loader Operation Sequence - Rotating Cylinder Concept

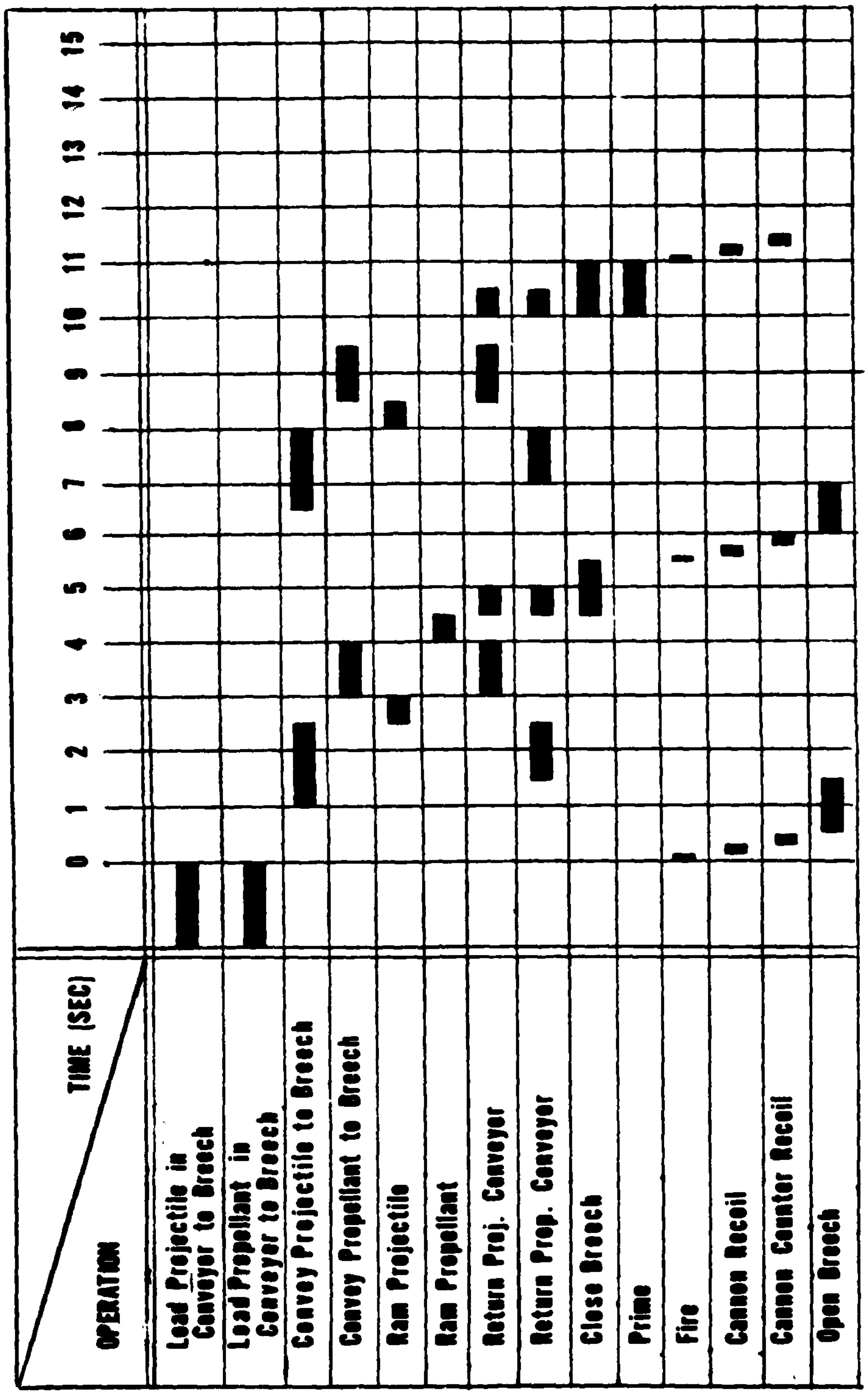


Table 4-3 Loader Operation Sequence - Single Chain Conveyor Concept

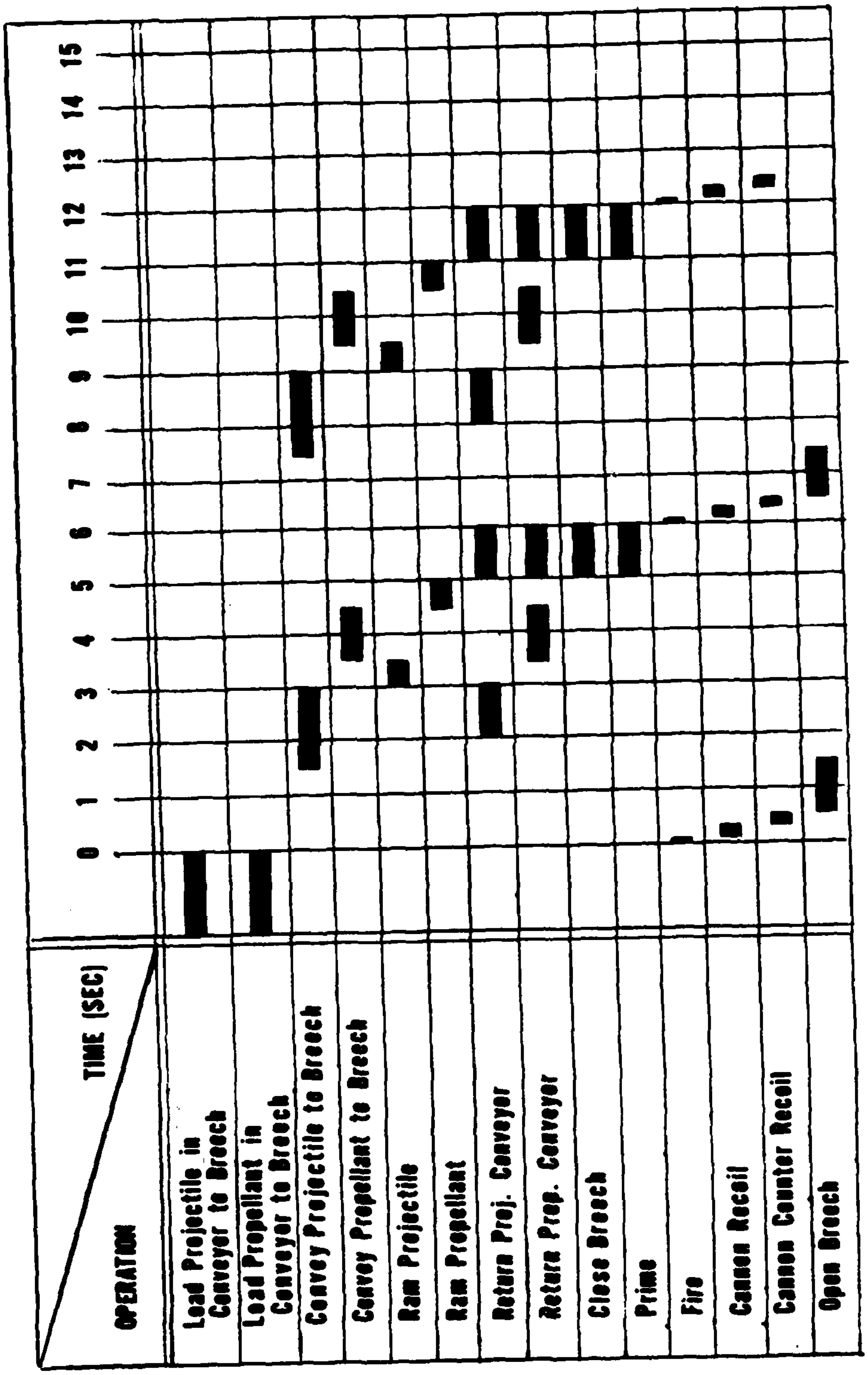


Table 4-4 Loader Operation Sequence - Dual Chain Conveyor Concept

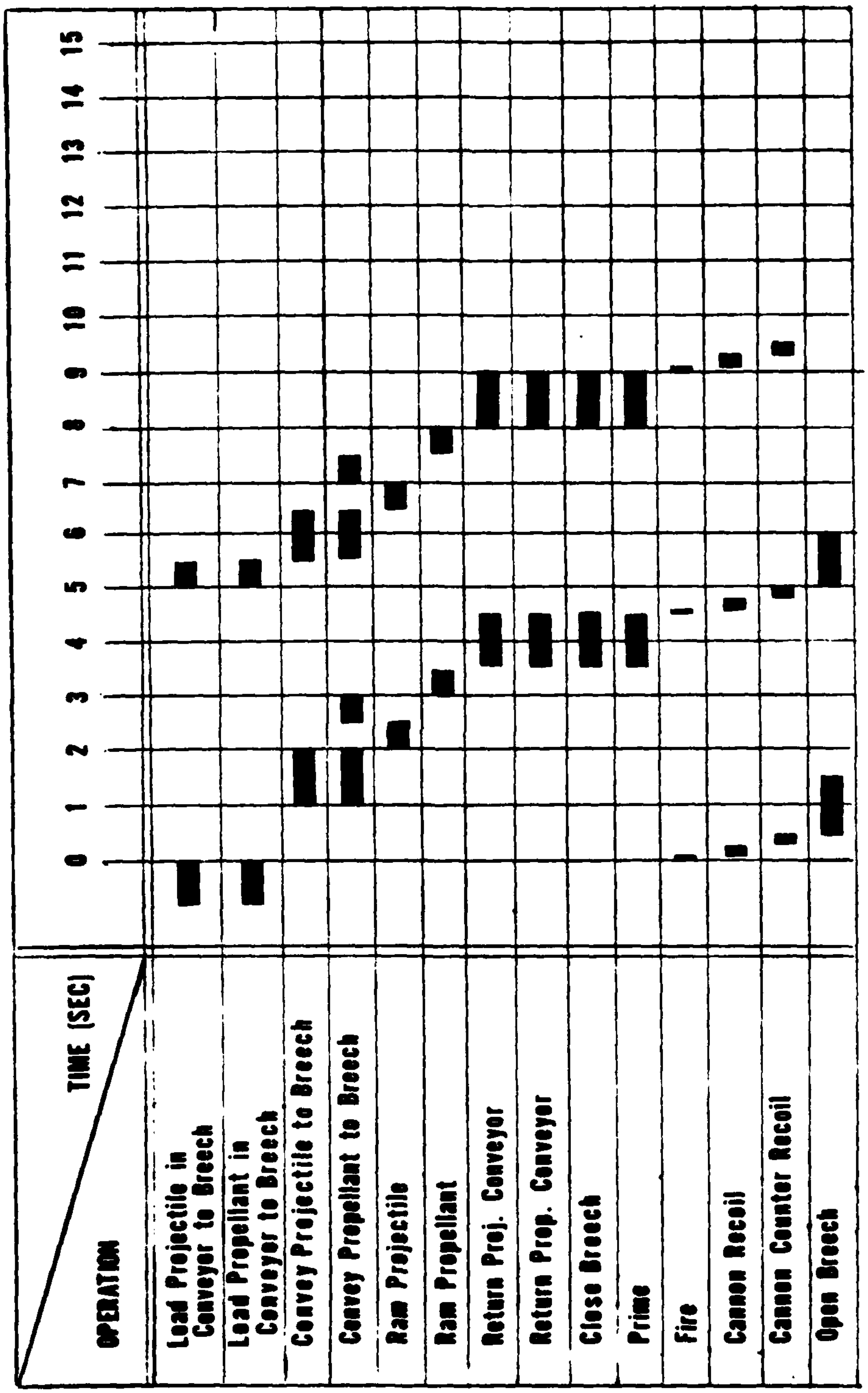


Table 4-5 Loader Operation Sequence - Guided Ramp Conveyor Concept

rounds would be fed to a single convenient unstowing point; if the rounds are difficult to remove, the other concepts would be better.

4.4.7 Space Required

For all of the loader concepts, the conveyor or a portion of it must be moved from the loading position so as not to interfere with the gun recoil at lower elevations. This requires additional unobstructed space within and/or without the current space. For the rotating cylinder and single chain conveyor concepts, the entire assembly retracts, while for the dual chain conveyor and guided ramp conveyor, only the tray that supports the rounds for ramming must be withdrawn.

The guided ramp conveyor does not intrude into the present crew compartment, while the rotating cylinder intrudes only slightly, mostly during loading. The chain conveyors intrude extensively.

4.4.8 Logistics

The Rotating Cylinder, Single and Dual Chain conveyors are each rearmed by manually replacing rounds in each stowage tube. The Guided Ramp Conveyer concept offers potentially better options. Rounds could be fed from a support vehicle through rear bustle doors directly to the bustle-to-breech conveyor for firing. The rounds could be fed through rear bustle doors onto the lateral conveyor which could transfer the rounds to the propercolumn, where they would be manually removed and stowed in their proper location, or rounds could be fed in through the top of each stowage column and positioned by the gravity feed mechanism. In this method, several stowage columns could be rearmed simultaneously, reducing the time required to rearm.

The actual total number of available rounds stowed has not been determined for the concepts since this would be limited primarily by space, weight and survivability limitations. However because of the stowage system design geometries the individual isolated stowage tubes allow a tighter pack.

4.4.9 Weight

It is estimated that the guided ramp loader would weigh approximately 3000 lbs. Weights were not estimated for the other loader concepts.

4.5 SUBSYSTEM EVALUATION

4.5.1 Cammed Guide Plates

The advantages of the cammed guide plate concept are that it: utilizes simple mechanical movements (captured roller ramps); captures the round through 90° of its circumference; locates the rounds at precise intervals; occupies little vertical space; can be modified to contact a large surface area on the round by adding parallel rows of similar interconnected guide plates; and advances the rounds simultaneously with quick, short movements. The disadvantages of this concept are that: the guide plates act independently, which requires some control logic; the rounds are raised and lowered which consumes power.

4.5.2 Oscillating Guide Plates

The advantages of the oscillating guide plate concept are that it securly captures the round, locates the rounds at precise intervals; occupies little vertical space; and advances the rounds simultaneously with quick short movements. The disadvantages of this concept are that it is somewhat complex requires control logic and supports the rounds with a limited area.

4.5.4 Twin Lead Screw

This concept is also relatively simple to operate but is relatively high, complexly shaped, difficult to position rounds at precise intervals, and does not adequately support or capture the rounds.

4.5.5 Opposed Crank Lateral Conveyor

This concept utilizes simple mechanisms, adequately captures and supports the rounds, but is relatively high.

4.5.6 Chain Conveyor with Locating Fingers

This concept is moderately simple, but is relatively high and difficult to locate at precise intervals.

4.5.7 Bustle-to-Breech Conveyors

The distance from the bustle to the rotated breech is relatively long. The axis of the breech lies in a different plane than the bustle floor. The howitzer also recoils through a straight line path from the center of the bustle floor to the rotated breech. Therefore, the bustle-to-breech conveyor must transport the projectile and propellant to the breech quickly, align them with the axis of the breech, and then move out of the recoil envelope.

Straight, single tray quided conveyors would need to retract, travel to the breech twice and have a complex mechanism to tilt the rounds for ramming. The fixed guide ramp that shuttles laterally with two trays adequately solves these problems.

4.5.8 Rammers

The geared rod concept is mechanically simple, however, in order to minimize space requirements behind the breech, the projectile would have to be rammed in two stages. The rear of the projectile could be rammed to the mouth of the breech with the rammer finger on the first stroke, the hammer shifted and the projectile rammed in further to accommodate the propellant with the front of the geared rod.

Although the zipper chain rammer is more complex, it can ram the projectile to the depth in a single stroke and then ram the propellant with a shorter stroke.

4.6 EVALUATION SUMMARY

The guided ramp loading system appears to be the most favorable loading system considered in that it is the safest for the crew to operate, requires less crew support, has the highest rate of fire and the largest number of ready rounds.

The gravity feed system was chosen because it stows the rounds reasonably well and passively advances them to the lateral conveyor. The cammed guide plate lateral conveyor was chosen primarily because it is relatively low and utilizes simple mechanical movements. The bustle to breech conveyor was chosen because it transfers both a projectile and propellant simultaneously and aligns them with the breech in a simple manner. The zipper ram was chosen because of the limited space it required behind the rotated breech and its capability to ram the projectile to its proper depth in one stroke.

5.0 ROTATING BREECH SEALS

5.1 SEAL REQUIREMENTS

The sealing mechanism for a 155mm Howitzer Rotating Breech must have the following characteristics.

- o Capable of cycling open and closed three times in ten seconds.
- o Capable of withstanding breech pressures of 60,000 psi.
- o Capable of operating at -50^{o}F thru +160^{o}F ambient.

In addition, the following constraints have been imposed upon the design. The seal:

1. must accommodate .005 to .011 inch axial deflection resulting from movement between the breech and the rotating member.
2. must be easily replaceable.
3. must be applicable to both front and rear faces of the rotating member.
4. must accommodate independent rotation of the breech, for emergency unloading, without excessive friction.
5. design must consider RAM.

5.2 SEAL CONCEPTS

The following summarizes those sealing concepts considered most applicable to the 155mm rotating breech cannon. Since the subject of high pressure sealing is extremely diverse, a comprehensive survey is beyond the scope of this program. Salient seal designs and techniques, however, have been briefly described below. The varied sealing techniques, which have been successfully used in uultra-high pressure applications, can be generally categorized as follows:

5.2.1 Elastomer Seal with Metallic Anti-Extrusion Rings

The majority of seal designs fall in this category. The elastomer provides the initial seal. With application of high pressure, metallic backup rings are energized to prevent extrusion of the elastomeric seals. The design of the backup rings takes many forms, from simple types to metallic seal rings which completely encapsulate the elastomeric seal under high pressure

application. In many of the designs the metallic backup or seal rings, when energized, not only encapsulate the elastomer seal to prevent extrusion, but also function as metal-to-metal seals. Many of the successful seals used in Liquid Propellant Gun (LPG) designs to date have utilized such seals. Examples of this technique are given in figures 5-1 through 5-3. Figures 5-1 and 5-2 show various static and dynamic applications of the elastomeric seal with metallic or hard plastic backups. Seals of this type, particularly the "D" ring, "O" ring and "T" ring have been used successfully in LPG's above 60,000 psi.

Figure 5-3 shows the type of seal, based upon an elastomer and backup, which is used in almost all bag loaded guns. It is well suited to conventional gun design employing substantial axial preload and little deflection between breech and barrel during firing.

5.2.2 Reduction of Pressure Drop Across Seal by Use of Multiple Seals

Since one of the primary failure modes of high pressure seals is excessive leakage caused by the high pressure differential across the seal, a technique successfully used is to reduce the pressure drop across each seal by using multiple seals, as shown in figure 5-4. In more elaborate schemes, the intermediate pressure between multiple seals is controlled by external pressurization to limit pressure drop between seals. While successful in many commercial applications, this technique generally results in a large increase in seal length. Application here would be difficult, hence this technique has not been considered further.

5.2.3 Balanced Pressure Seals

One technique for sealing against high pressure is to pressurize the rear of the seal with an inert fluid to a pressure equal to or higher than the high pressure environment. The shaft seals of deep submergence vehicles are based on this principle. In general, this technique is too complex for artillery applications and thus has not been considered further.

5.2.4 Metal-to-Metal Seals

Self-energized metal-to-metal seals have been applied to numerous revolver-type automatic cannons. To function properly, the seal surfaces must be smooth and free of foreign particles. The seal should also be lightly preloaded to insure the sealing lip is "set" before the onset of high pressure.

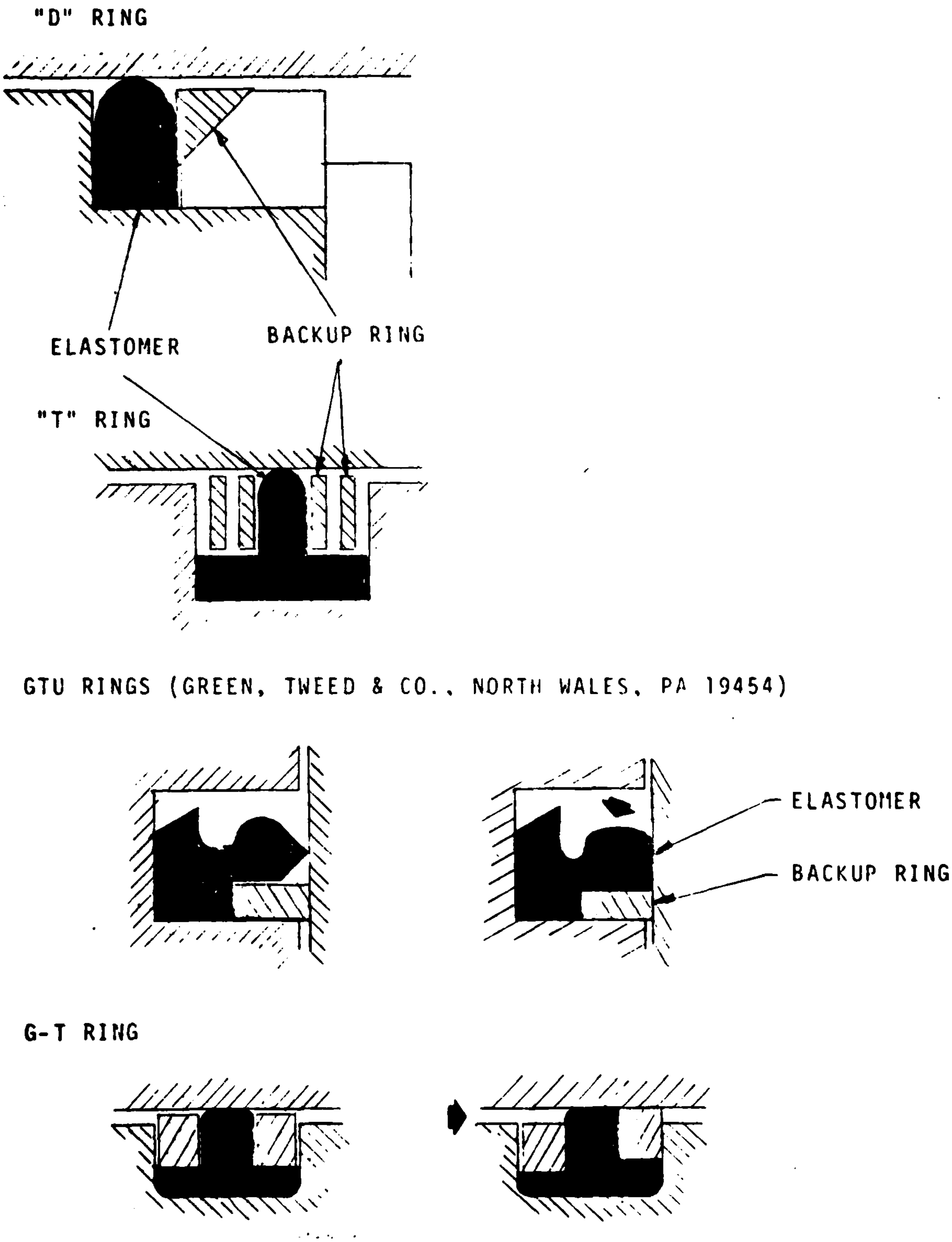


Figure 5-1 Elastomeric Seals with Metal Back-up

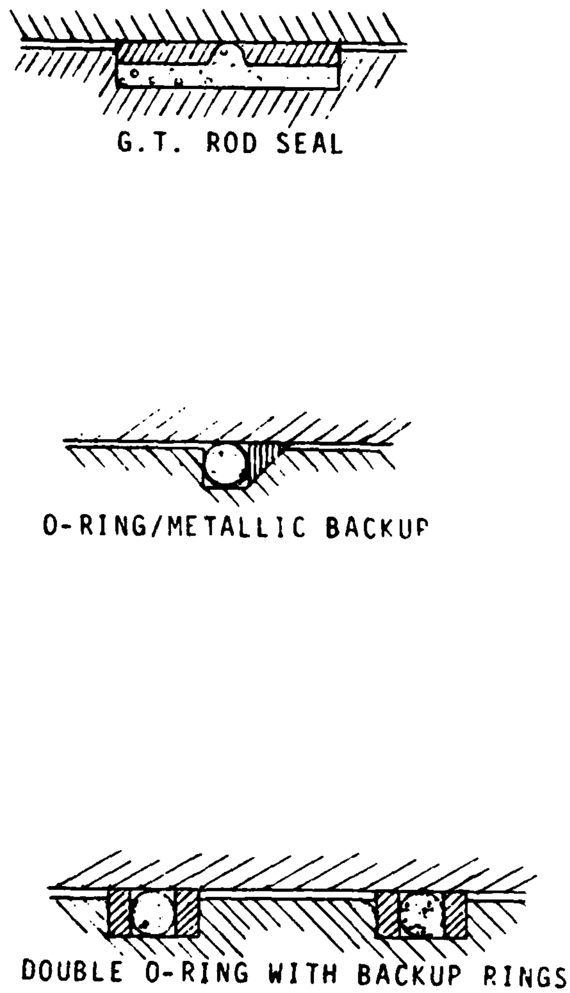
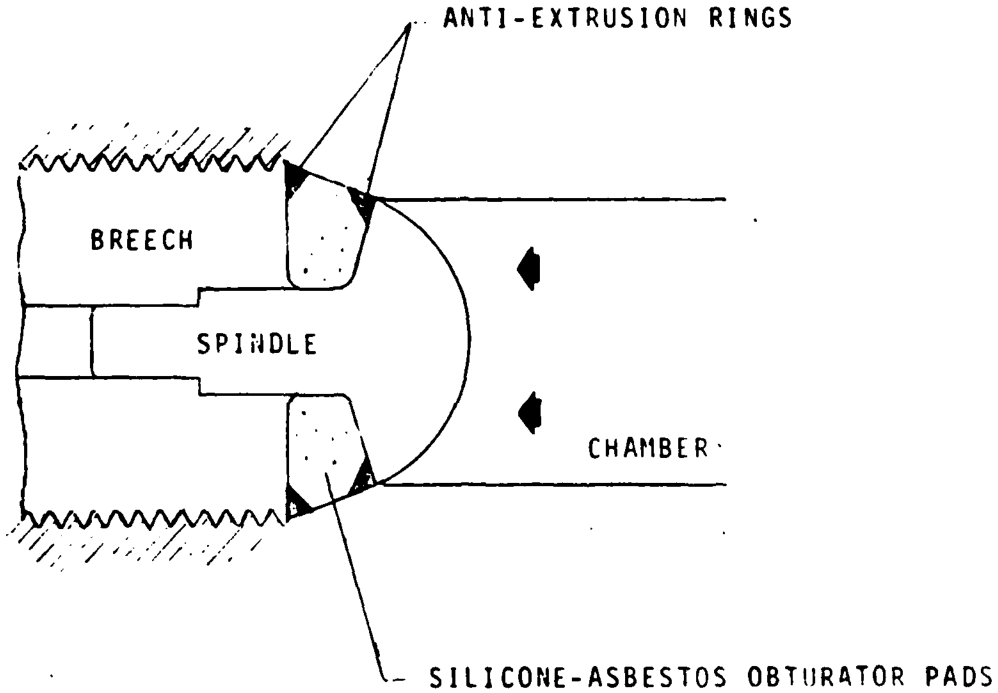


Figure 5-2 Elastomeric Seals with Metal Back-up

DEBANGE OBTURATORS (USED IN ALL BAG LOADED GUNS)



TYPICAL 175mm GUN OBTURATOR

Figure 5-3 Debange Orburators

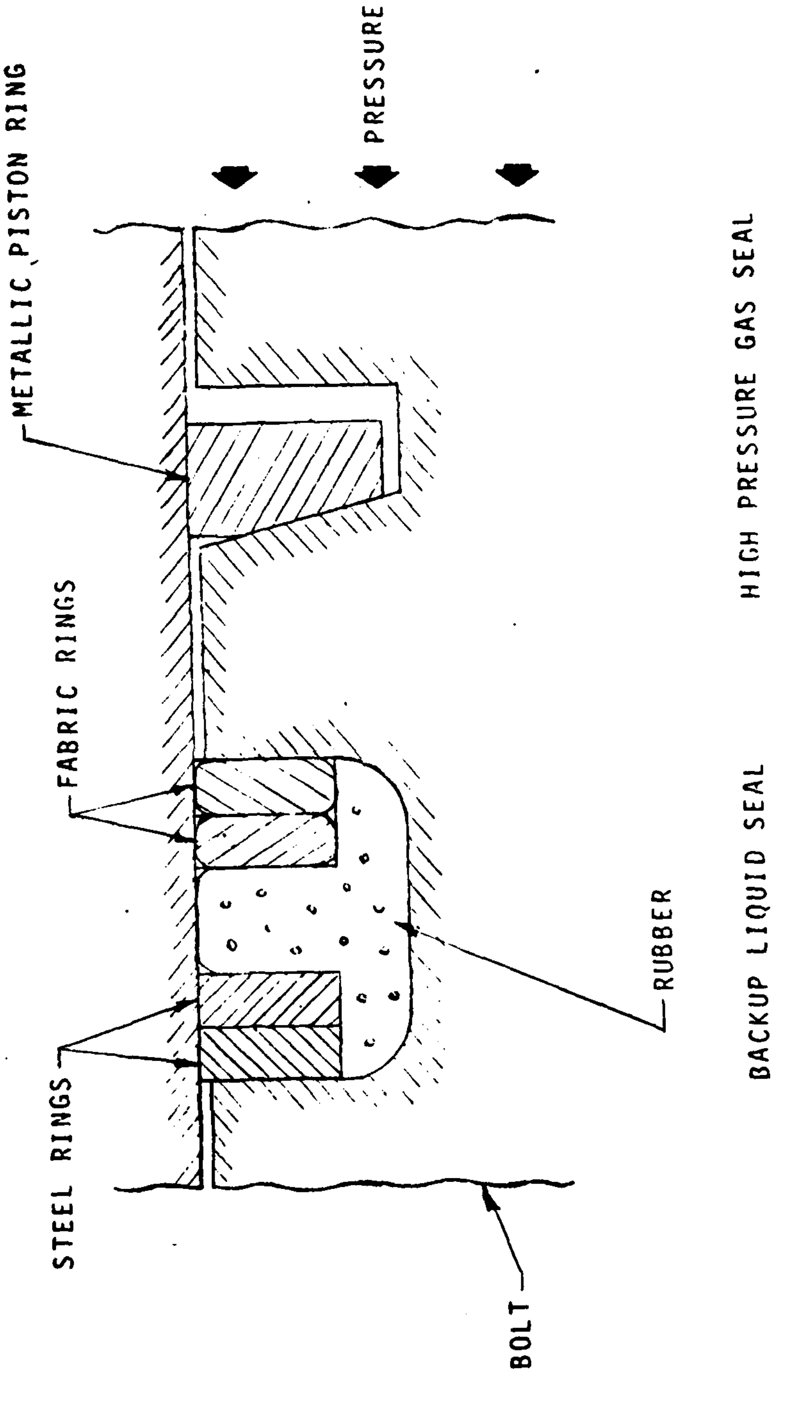


Figure 5-4 Ring with Bevelled Back-Step Piston Ring

A variety of metal-to-metal seal configurations which have been successfully applied at gun pressures are shown in figures 5-5 through 5-8. Of these, the most significant, and the design most applicable to the 155mm rotating breech, is the "L" seal. As shown in figure 5-8, this seal was developed to replace the labyrinth seal originally employed in the 20mm M-39 automatic cannon. The application has been sufficiently successful that virtually all cannon caliber revolver-type weapons, using either cased or caseless ammunition, now employ this general seal design. Accordingly, it has been chosen as the preferred design for the 155mm rotating breech cannon with a wedge-type configuration as an alternate.

5.3 DESCRIPTION OF DESIGN

Two seal designs are shown in figures 5-9 and 5-10. The first is a modification of the "L" seal and the second an adaptation of a Pulsepower Systems Inc. wedge seal used to seal concentric cylindrical surfaces at pressures exceeding 100,000 psi.

Both designs are installed in grooves in the breech and barrel. Since the grooves are machined into a cylindrical suface, the mating seal will have a changing cross section. This is not considered to be detrimental to sealing ability and facilitiates the groove machining.

The seals are held in place by a series of bolts which provide the initial seal preload and allow the seal to follow a .007-inch separation between the surfaces. The bolts are made of steel and are 1.375 inches long. If beryllium copper is used, the bolt will allow as much as .011 to .012-inch separation. To allow larger clearances, the bolts can be made longer, or lower modulus materials can be considered.

Larger clearances can be accommodated if the seal is permitted to slide on the bolts by providing clearance under the heads. This method has disadvantages however in that the seal cannot be preloaded and reliability may be affected by relative motion between the sealing member and the bolts.

Figure 5-9 shows the modified "L" seal design. The seal is stepped, as shown, to fit the contour of the breech groove. The face of the seal is machined to match the cylindrical contour of the chamber. The inside diameter is machined to provide two lips as shown. The heavier lip bottoms in the groove when the bolts are preloaded. This provides an initial seal across the back of the seal which permits pressure to force this lip against the inner cylindrical wall of the groove.

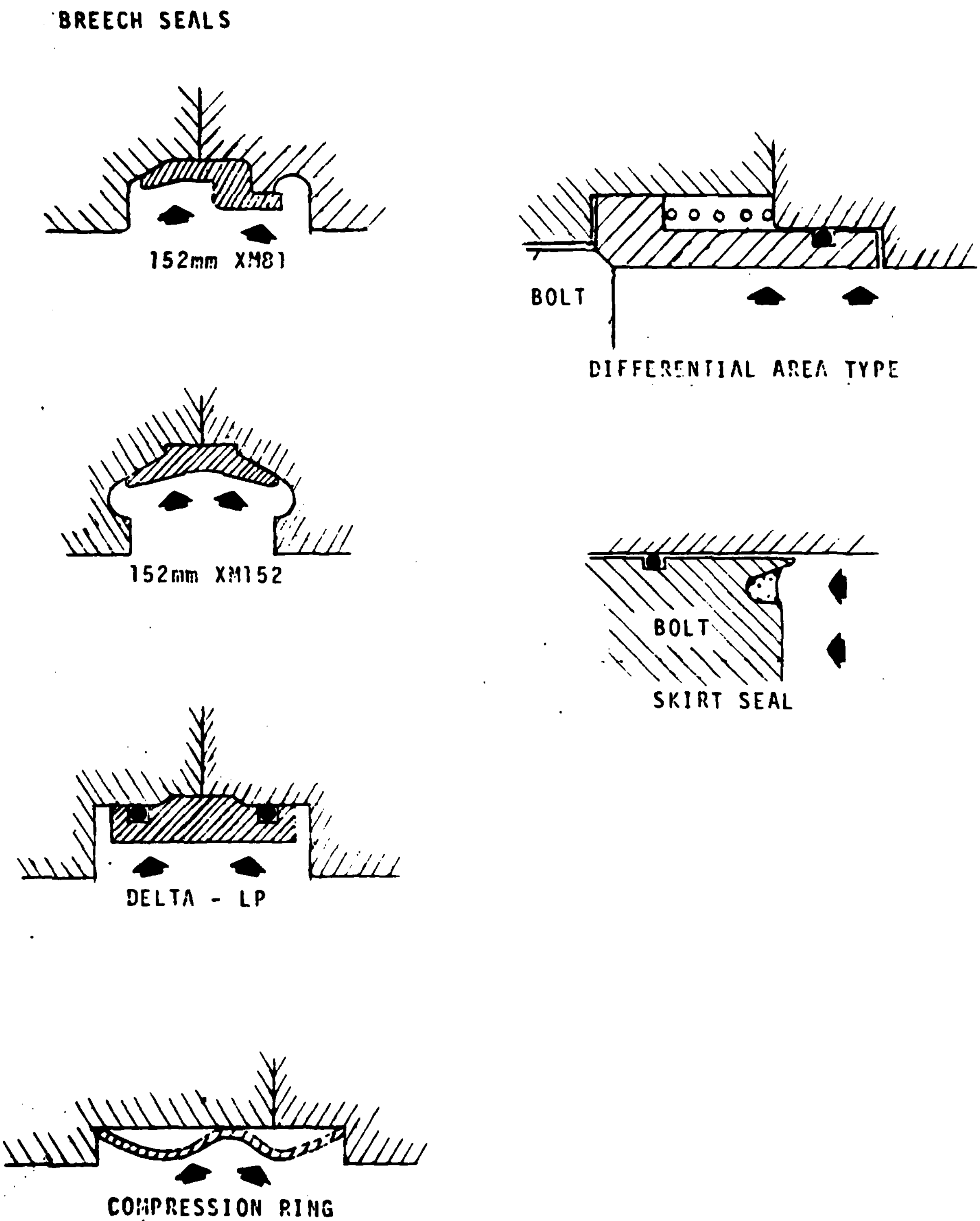
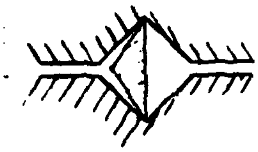


Figure 5-5 Metal-to-Metal Seals

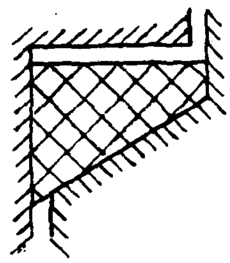
SOLID METAL HEAVY CROSS SECTION GASKETS

1) DELTA



USE FOR 5,000 psi AND UP
PRESSURE ACTUATED

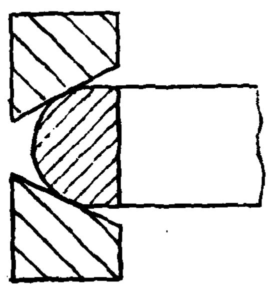
2) BRIDGEMAN GASKET



CONSIDERED BEST FOR 2,000 psi AND UP

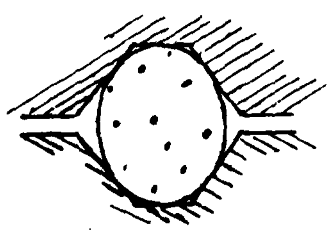
SELF-ACTUATED - SEALING FORCES REQUIRE IS MODERATE AND ONLY TO EFFECT INITIAL SEAL

3) LENS RING



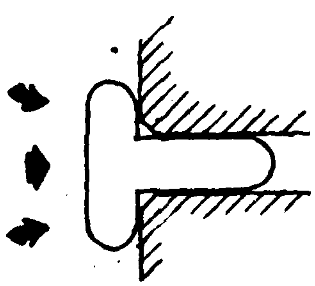
TIGHT TOLERANCES
20° TAPERED SURFACES
REQUIRES HIGH COMPRESSIVE LOADS TO SEAT SEALS

4) OVAL



MODERATE BOLT LOADS GIVE HIGH GASKET LOADS

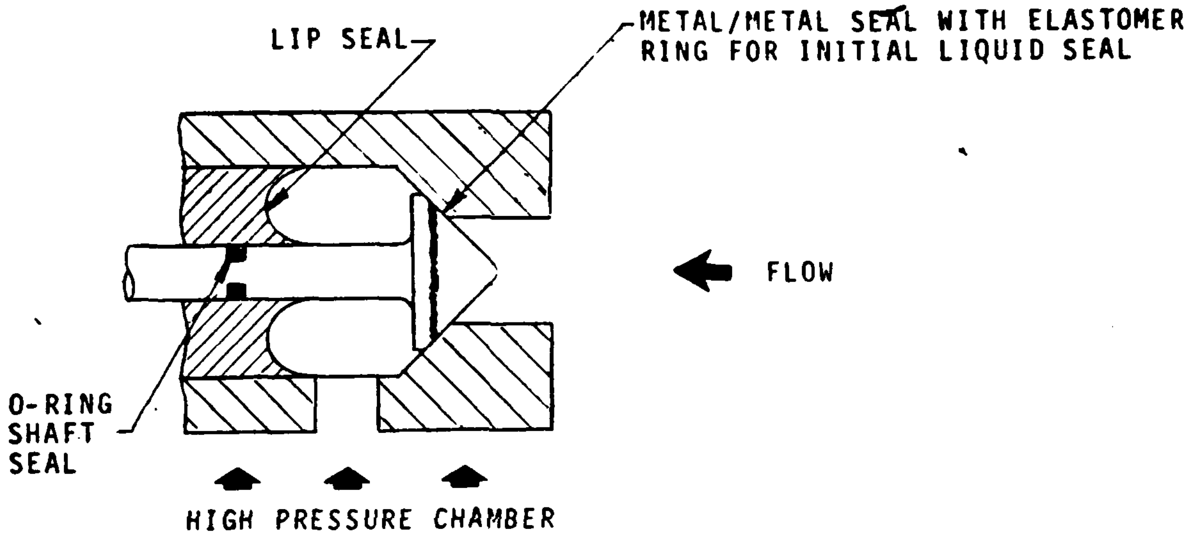
5) STUD SHAPED



REQUIRES INITIAL LOAD TO SET GASKET - IS THEN PRESSURE ACTUATED

Figure 5-6 Metal-to-Metal Seals

SPOOL POPPET VALVE



FACE SEALS

RING SPRING WITH ELASTOMER SEAL

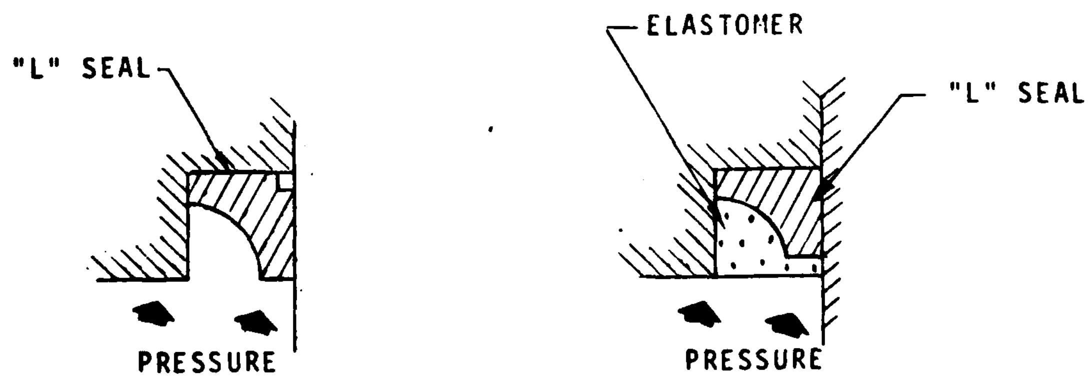


Figure 5-7 Metal-to-Metal Seals

RING SEAL FOR M-39 REVOLVER CANNON

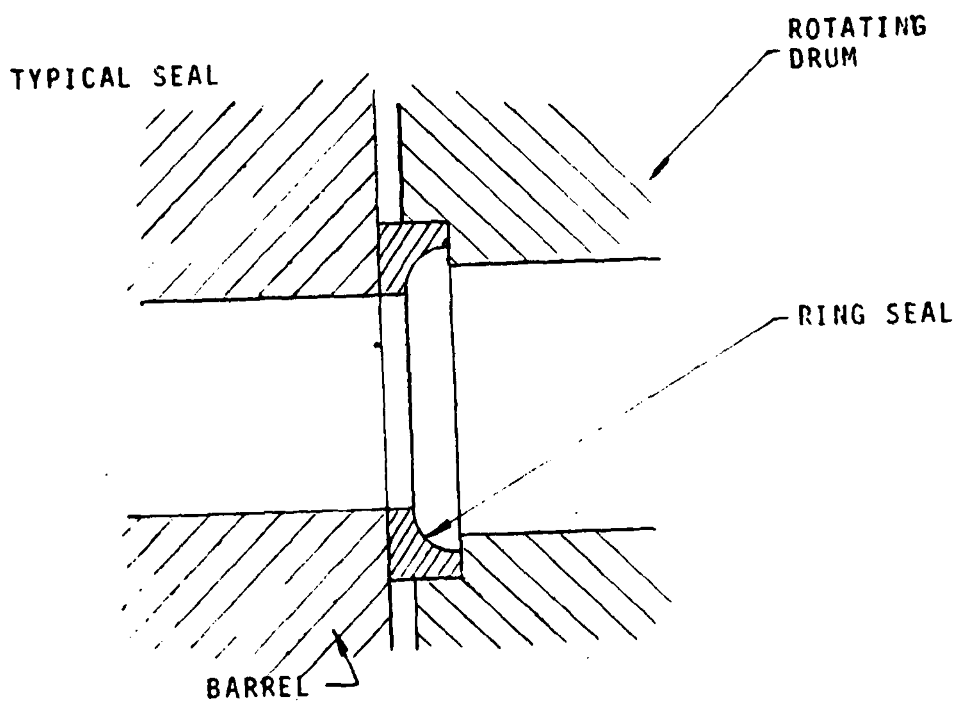


Figure 5-8 Ring Seal for M-39 Revolver Cannon

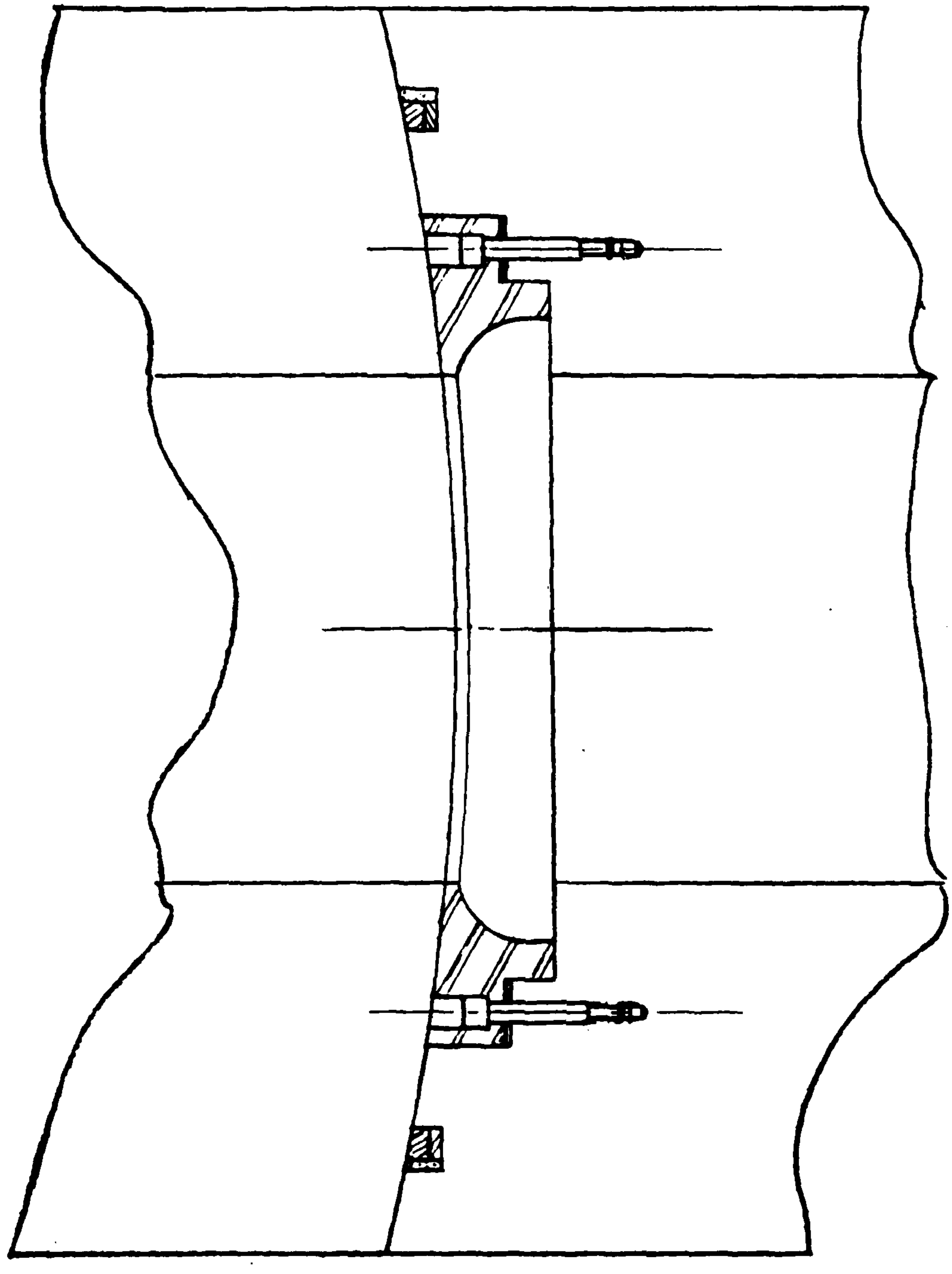


Figure 5-9 "L" Seal

It will be noted that there is a small clearance between the seal and the groove at the bolt interface. When the bolts are torqued to their initial preload, a torsional stress is placed on the seal cross section which preloads the sealing lip against the cylidrical surface of the chamber. This provides initial setting of the seal. Gun pressure then deflects the sealing lip against the chamber surface. Pressure forces the sealing ring to follow the separation between the breech and chamber or between the chamber and barrel. In addition, since the pressure is applied eccentric to the bolt circle, a couple is applied to the sealing ring which also forces the sealing lip against the chamber surface.

The seal design shown in figure 5-10 is a modification of a high pressure seal for two concentric cylindrical surfaces. The primary seal is effected by a steel ring which makes contact with the cylindrical surface of the chamber. The sealing surface of this ring is forced against the chamber by means of a second ring which mates to the first along a 45° ramp. This second ring is made from beryllium copper (BeCu) which has a modulus of approximately 19×10^{6} psi compared to 29×10^{6} psi for the steel ring. The BeCu ring thus can expand along the ramp when pressurized by the internal pressure without taking a permanent set since its deformation is almost equal to that of the steel ring. The wedging action of the BeCu ring forces the steel ring sealing surface against the chamber surface, as mentioned above. As with the "L" seal, the assembly is held in a groove by a series of bolts. These bolts are preloaded sufficiently to effect the initial seal between the steel ring and the BeCu ring and between the copper ring and the bottom of the groove. It will be noted that there is a small clearance between the steel ring and the bottom of the groove to obtain this initial seal. The groove is simpler than that used in the "L" seal in that no step is required.

As in the "L" seal, the steel sealing ring will follow the chamber surface as it moves away from the breech or barrel under the pressure load. The displacement that can be tolerated is a function of the available bolt deflection which, in turn, is a function of bolt length and material. The present design allows a deflection of .007 if steel bolts are used or .011 for BeCu bolts. These deflections can be increased a small amount and still maintain an adequate seal because under load the steel ring will have a torsional deflection. It will be noted that in both designs the seal inner diameter is kept as close to the bore diameter as possible. This minimizes extension loads on the external breech-to-barrel load carrying structure. Assuming the seal is effective at bore diameter, the axial extension load at 60,000 psi is 1.755×10^{6} lbs.

A secondary consideration for a sealing surface, which is as close to the bore diameter as possible, is cleanliness, since the seal wipes over the cylindrical surface during the loading

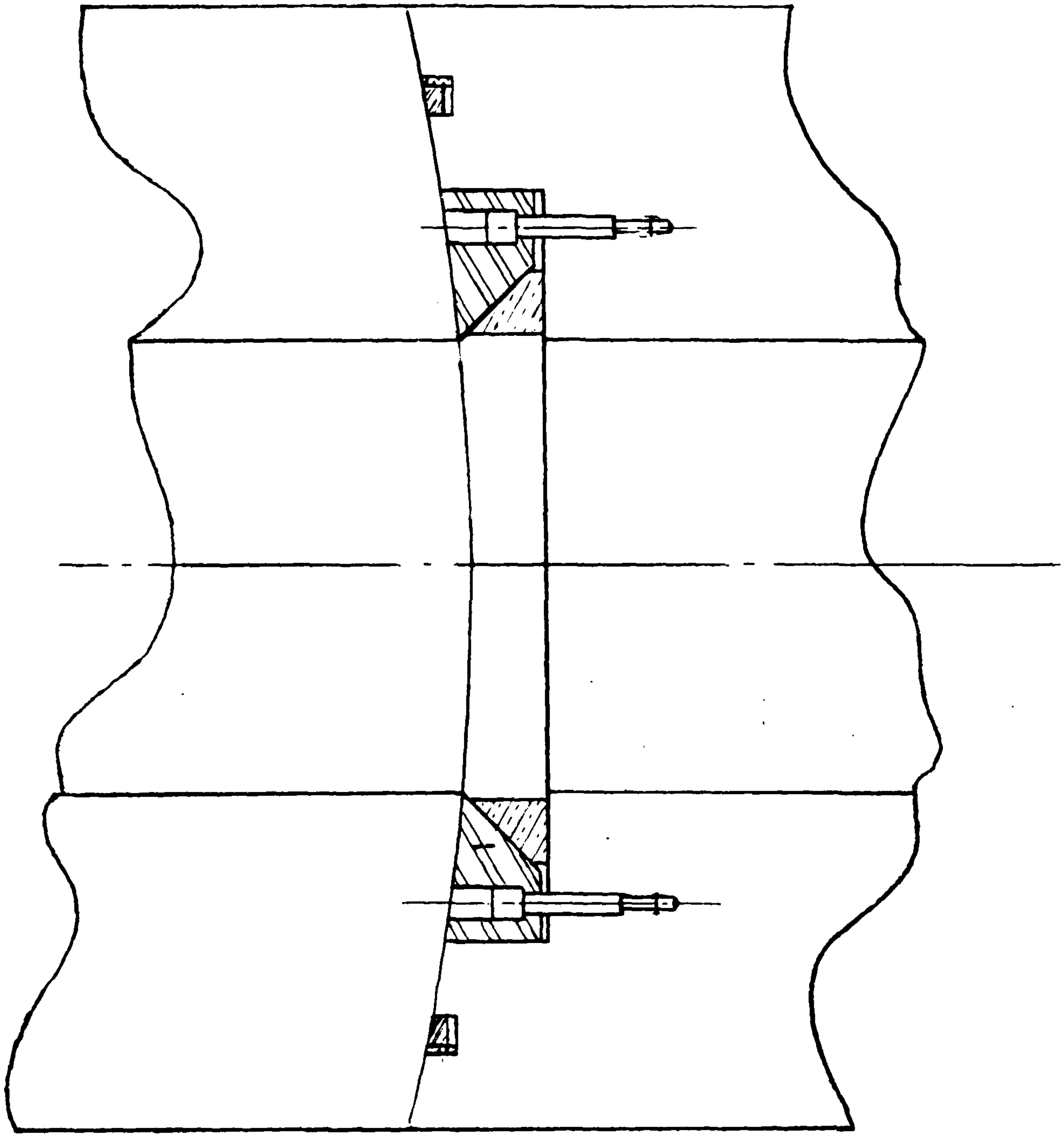


Figure 5-10 Wedge Seal

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CONCEPTUAL DESIGN OF A ROTATING BREECH AUTOMATED AMMUNITION HAN--ETC(U)
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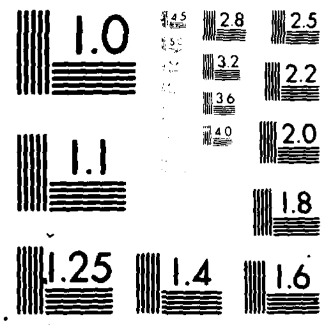

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

cycle. There can be residue buildup from burning powder on a narrow ring between the bore and the true sealing diameter. This must be scraped off during the loading cycle by the lip of the seal.

For this reason, the seal is made of a material that can be heat treated to high hardness, either 4340 steel or one of the precipitation hardening stainless steels such as 15-5. To aid in keeping the sealing surface clean and lubricated, a combination scraper and lubrication ring is incorporated external to the seal carrying groove. This also serves to keep foreign material out of the seal area whenever the gun is closed.

Figure 5-11 illustrates a seal configuration that was developed during the early stages of the design program, and is included on several of the layout drawings. Breech modifications required to adapt the breech to use the preferred "L" type seal are detailed on drawing No. 3032-001. The seal is detailed on drawing No. 3032-002. Both drawings are included in the drawing package that accompanies this report.

5.4 SUMMARY - ROTATING BREECH SEALS

It is considered that either of the two seal designs meet the criteria set forth in section 5.1.

These are:

a. Accommodate sealing surface separation of .005 to .010 during firing at pressures up to 60,000 psi. Both designs can accommodate .007 separation with steel retaining bolts and as much as .012 with beryllium copper bolts.

b. Neither seal design will be damaged by opening and closing the chamber at a rate of three times in ten seconds.

c. Since no elastomers are used in either seal design and since all the materials used are similar and will have the same coefficient of expansion, the seals should not be affected by the temperature range of -55° to $+160^{\circ}$F. If beryllium copper bolts are used the differential expansion must be taken into account when calculating the initial preload.

The applications of the other type seals considered are summarized in Table 5-1.

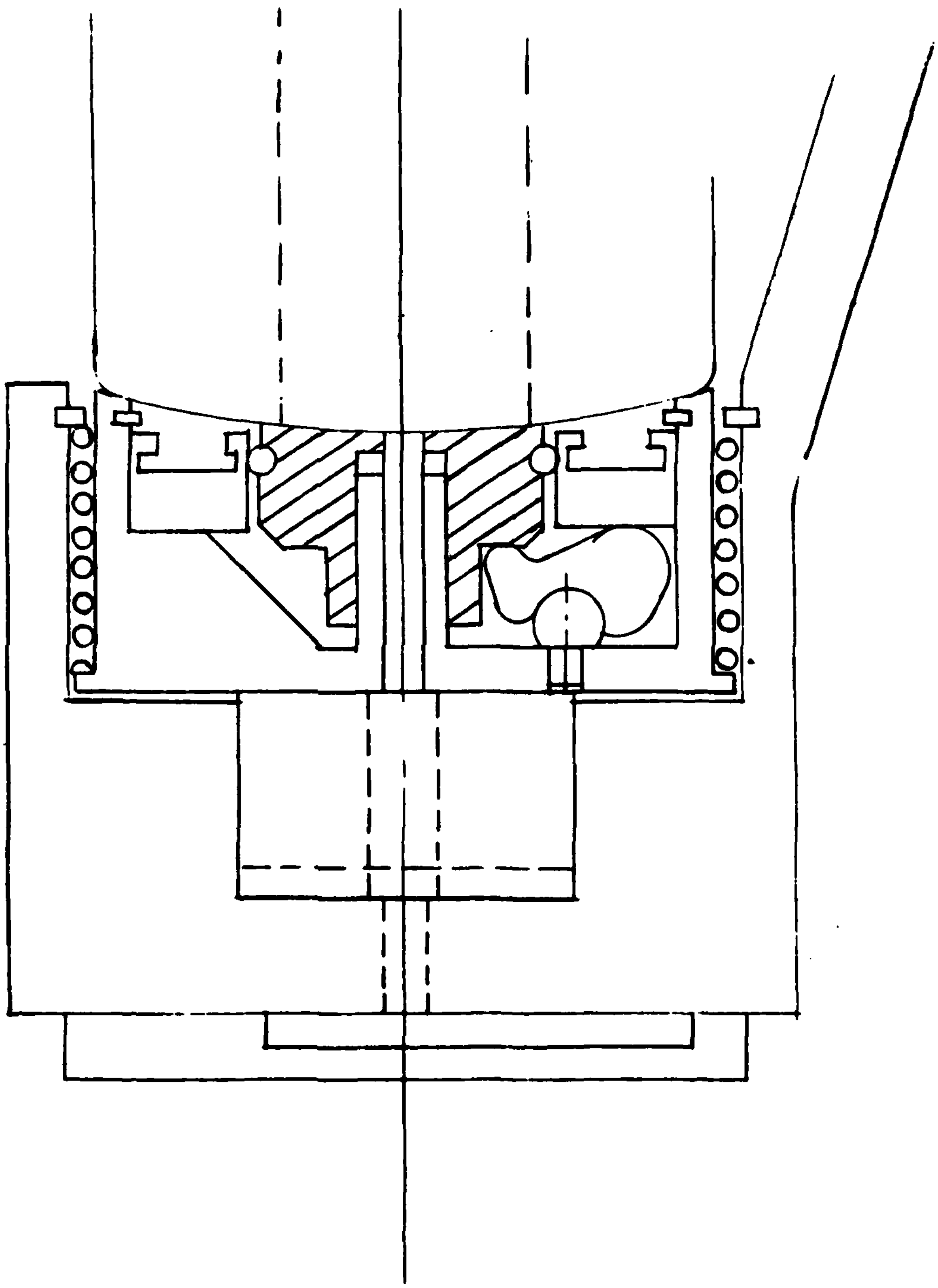

Figure 5-11 Piston Seal Concept

TABLE 5-1
Seal Applications Summary

Figure No.	Type of Seal	Application	Characteristics
ELASTOMER SEALS			
5-1, 5-2	Elastomer seals with metal back-ups	Liquid propellant gun chamber valves at pressures exceeding 60,000 psi, and hydraulic cylinders. Seals commercially available from Green, Tweed & Co., North Wales, Pa.	Low pre-load, can seal rough or dirty surfaces.
5-3	Debange obturator	Conventional bag-loaded artillery	Requires substantial pre-load
BALANCED PRESSURE			
	Balanced Pressure	Deep submergence vehicle shaft seals	Rear of seal is pressurized, complex
BEVELLED BACK - STEP			
5-4	Ring with bevelled back-step piston ring	Liquid propellant gun bolt seals	Modified palmetto G.T. ring
METAL-to-METAL SEALS			
5-5	Breech seals	Various large caliber breeches	
5-6	Gaskets	Commercially available for static sealing applications	Solid, heavy cross section
	Delta	Gasket	5,000 psi and up, pressure actuated
	Bridgeman	Gasket	2,000 psi and up, moderate pre-load
	Lens ring	Gasket	Tight tolerances high preload
	Oval	Gasket	High gasket loads
	Stud shaped	Gasket	Requires pre-load
5-7	Spool poppet valve	Propellant inlet valve for 90mm L. P. tank gun	
5-7	"L" - seal		Adaptable to sliding surfaces
5-8	"L" ring seal	M-39, Oerlikon 304 RK revolver-type automatic cannon	Application of "L" seal
5-9	"L" - seal	Proposed "L"-seal adaptation for 155mm rotating breech concept	
5-10	Wedge seal	Alternative "L"-seal adaptation for 155mm rotating breech concept	Modified "L" seal with wedge ring to improve seal

5.5 SEAL PROBLEM AREAS

The rotating breech concept developed requires sealing the gun tube for firing. The primary purpose of the seals is to allow the pressure from the exploding charge to accelerate the projectile. The seals also prevent potentially injurious pressure buildups in the crew compartment and contain toxic gases.

The seal is broken for each loading cycle and exposed to a potentially contaminating environment. Dirt or residue may block the seal and become trapped between the sealing surfaces. Since there is a discontinuity in the bore at the seal or the breech may misalign with the gun tube, particles may be shaved from the projectile as it passes.

As the rotating band of the projectile passes the discontinuity at the seal it may not re-engage with the rifling in the same grooves. However, this is probably unlikely because the complex interface that the band passes over should allow rifling contact to be maintained throughout the transition.

Most seal concepts utilize breech pressure to activate the seal, so that there may be some period of time where the breech is pressurized but the seal material has not expanded sufficiently to seal the breech. Since the seals depend on flexing material, seal designs with non-uniform cross-sections may not seal adequately.

However, regardless of these potential problem areas, it is believed that they can all be overcome since similar seal designs are successful and in use.

6.0 BREECH CONTROL SYSTEM

The breech control system consists of the hydraulic/mechanical components and electronic circuits required to control the motion of the breech. The hydraulic/mechanical components include the energy storing piston and accumulator, controlled valving, the rotary actuator and breech sleeve. The electronic system monitors the location of the gun barrel, breech and reload position and controls the hydraulic input to the rotary actuator.

The rotary actuator that has been tentatively selected is shown in figure 6-1. Its torque output at 3000 psi is 96600 in.-lb. which should be sufficient to quickly rotate the breech. The valving that controls the hydraulic input to the actuator should have a modulating capability, so as to tailor the hydraulic flow for smooth breech movement. This can be accomplished by either modulating the opening of a single valve or through several parallel valves that are opened or closed independently.

The spring loaded energy storing piston and accumulator will be sized to supply an adequate store of energy. The counter-recoil portion of the gun's recoil/counter recoil stroke was chosen to charge the accumulator since its duration is much longer than for recoil, allowing a more controlled charge.

Hydraulic System Operation (Figure 3-13).

As the weapon is fired, the gun recoils; as it returns to battery during counter recoil, an arm on the breech housing engages a spring loaded piston which pumps fluid through check valve 'A' through solenoid operated valve 'B' charging the accumulator. The recoil piston returns to start position drawing fluid from the replenisher through check valve 'C'. Valve 'B' is actuated by an electronic signal from a timing device allowing the accumulator to pressurize the rotary actuator which will bring the breech against an external stop at the load position. The rotary actuator remains pressurized until loading is completed. Once loading is completed, an electronic signal from a timing device actuates valve 'B' reversing the rotary actuator which returns the breech to the ready to fire position. Valve 'D' is then actuated by an electronic signal from a timing device to dump the excess fluid from the accumulator into the replenisher.

The gun is now ready to fire.

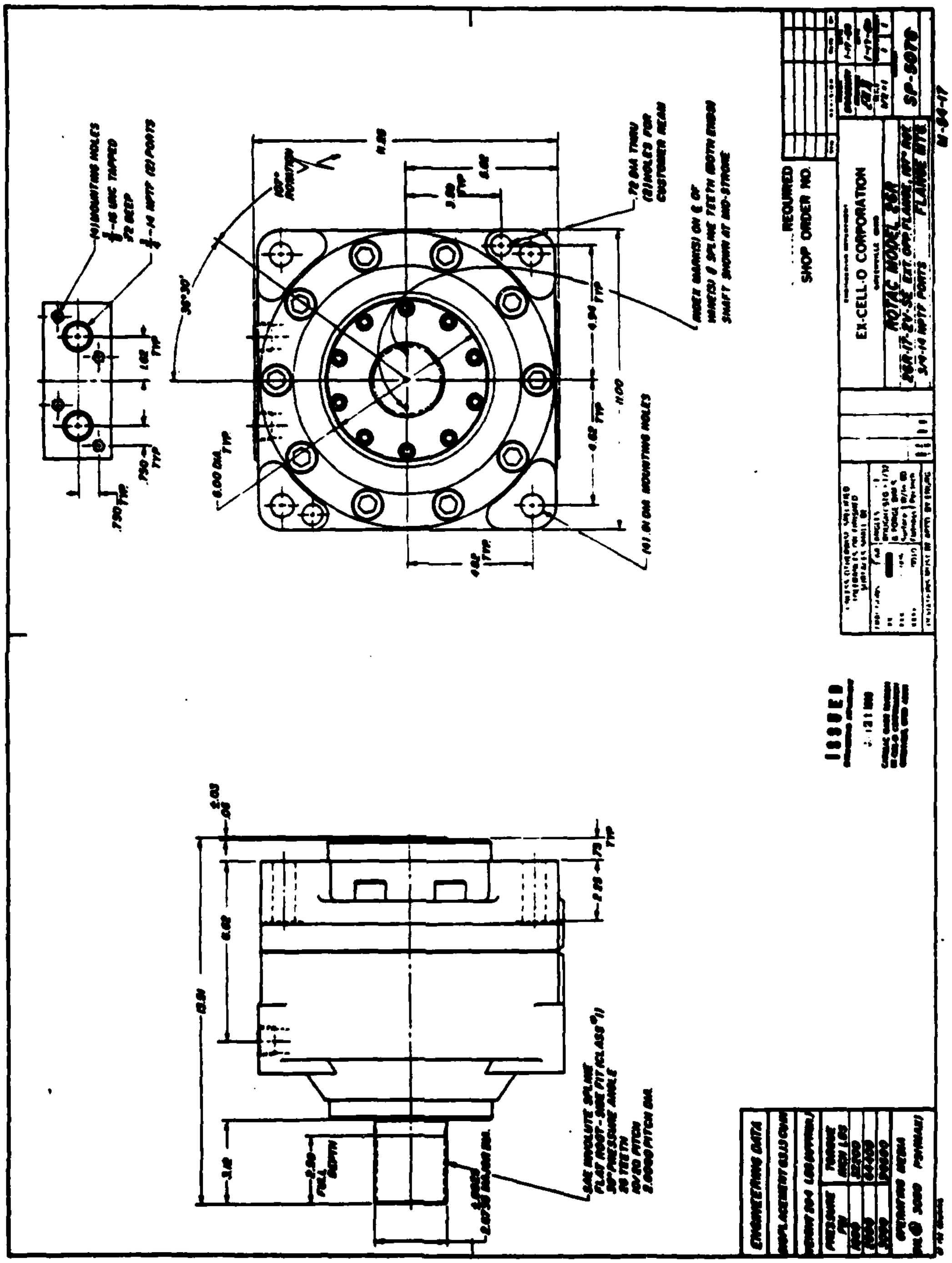

Figure 6-1 Hydraulic Rotary Actuator

On counter recoil, the hydraulic rotary actuator is actuated, rotating the breech to the loading position of the automated loader.

The electronic system is shown in figure 3-14. Sensors continuously monitor and signal the elevation of the barrel and the position of the breech assembly. There is also a fixed reference signal which corresponds to the loading position of the breech. The breech control electronics system is an integral part of the fire control circuit. The circuit must also interface with the loading mechanism to ensure that the entire ammunition handling system operates in the proper sequence.

The automatic control system can be overridden to manually control the operation of the breech and loading system.

7.0 PREFERRED CONCEPT

The rotating breech concept proposed by Chrysler to meet the 155mm howitzer automated loader requirements (figure 7-1) is capable of firing a three round burst in an estimated time of 10 seconds. The sustained firing rate is limited only by the ability of the crew to fuze and zone the ammunition.

With projectile fuzes installed and the correct propellent zone charge loaded in the consumable propellent cannisters, additional rounds beyond the initial three round burst can be fired at five second intervals.

Concept characteristics are described in detail in sections 3 and 4 of this report and are graphically defined in the concept drawing package that accompanies this report. This section describes the primary features of the preferred concept as well as the interaction between concept subsystems.

7.1 CONCEPT DESCRIPTION

The preferred concept is comprised of three sections - a bustle magazine section, an ammunition loader and the rotating breech section. Ammunition (projectile and propellent cannister) is stowed in the bustle magazine, automatically transferred from the bustle magazine to the overhead loading position and rammed into the breech by the ammunition loader, and rotated to the firing position by the breech mechanism.

The design of the bustle magazine section is similar to the design employed in the Swedish "S" tank. Projectiles are stowed in five vertical columns on one side of the bustle and Propellent cannisters are contained in five vertical columns on the other side of the bustle. The number of complete ready rounds stowed in the bustle could vary from 20 to 37 depending on the height of the cab bustle. On command from the gunner, projectiles are gravity fed from one of the vertical columns to a lateral conveyor on the bustle floor, where they are conveyed to the center of the bustle for loading. Each vertical column is separatly gated, so that the gunner can select any one of the five vertical columns (that could contain five different projectile types) as required. Similarly, propellent cannisters are simultaneously selected and transferred to the center of the bustle. If desired, propellent columns could also be equipped with controllable gates so that pre-zoned charges could be selected as required.

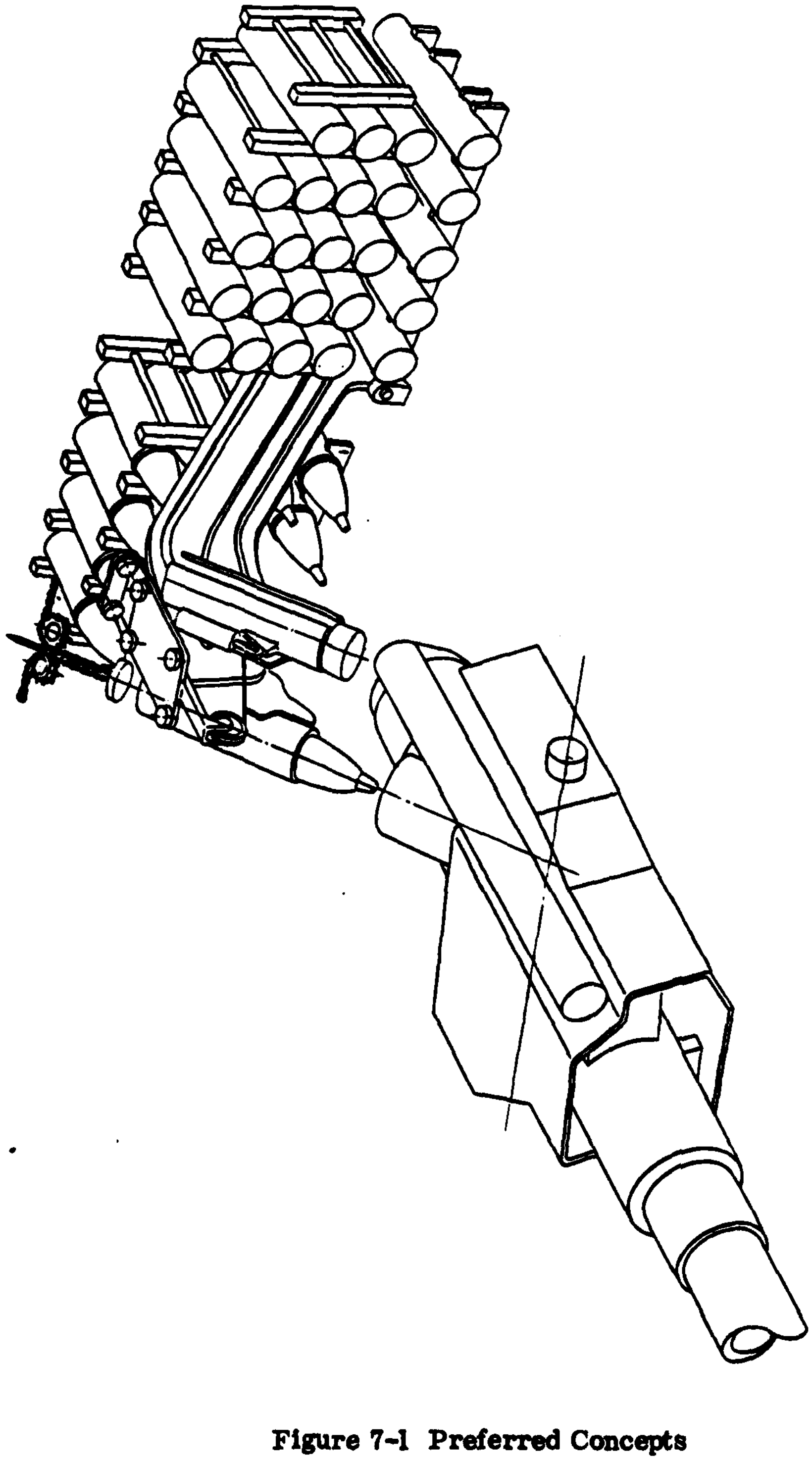

Figure 7-1 Preferred Concepts

Single Axis Rotating Breech with Guided Ramp Conveyor

At the center bustle position, the projectile and propellent cannister are simultaneously loaded on dual trays and hoisted to the overhead loading position, where they are rammed into the breech by a "zipper chain" rammer.

The zipper chain rammer is a flexible ramming mechanism that was devloped originally for the automatic loader on the XM803 tank program. The primary attribute of this mechanism is that it is flexible (in one plane), so that it can be configured to the available cab space and does not require an extended space behind the projectile. The chain consists of two separate chains that are flexible until locked together during the ramming stroke, when they link to form a rigid ramming rod. Ammunition is loaded by first ramming the projectile into the breech, moving the hoist to align the propellent with the open breech, then ramming the propellent cannister with a second shorter stroke.

The breech is rotated to the reload position by a rotary hydraulic actuator, which derives its power from the gun counter recoil force. Energy stored in the recoil mechanism during gun recoil is used to power a hydraulic piston, which in turn powers the rotary actuator.

Counter recoil force rather than recoil force is used as the power source to avoid the high peak force loads encountered during gun recoil.

7.2 HUMAN FACTORS AND SAFETY EVALUATION

Under normal conditions, the rounds will be loaded, rammed and primed automatically. This will allow the crew members to stand clear of the breech mechanism and gun recoil area during loading and firing operations.

For manually loading or extracting ammunition, a simpler design and procedure would be desirable. The current procedure is cumbersome.

A potential concern for crew safety is the performance of the breech seals. Faulty seals could expose the crew to noxious high pressure gases. Seal inspection criteria or devices to warn of seal deterioration in advance are desirable. Guards may also be required to shield the crew from moving parts or hydraulic lines that may rupture.

7.3 STRESS AND RELIABILITY EVALUATION

The automated ammunition handling system is more mechanically complex than the current manual system, and therefore probably will not be as reliable. Since the concepts are not yet well defined, the degree of reliability is uncertain, however, throughout the development of these concepts reliability was a prime concern. It was attempted to minimize the complexity of designs, the number of components, the movements required and the number of round transfers required.

The preliminary stress analyses contained in Appendix A indicate that the structure of both the breech and breech housing needs to be improved. In developing the concept, dimensions were chosen arbitrarily since developing a workable concept was emphasized. It is believed that all components can be sufficiently strengthened by adding more material and by slightly changing the designs of the components. However, the concept itself would remain unaffected.

Additional manual back-up systems and aids are required. For example, there are currently few provisions to manually ready the gun for firing in the event of the breech jamming in the loading position. However, there appear to be no insurmountable reliability problems.

7.4 ROTATING BREECH SEALS

The seal concpetual design program has resulted in two seal designs, either of which can meet the rotating breech requirements. The seals with beryllium copper retaining bolts are capable of accomodating sealing surface separations of as much as .012" at each of the two sealing surfaces, or a total of .024". It is believed that this calculation is conservative because it does not include the additional accommodation attributable to the torsional deflection of the steel ring under load. Preliminary stress calculations indicate that the total breech housing elongation will be excessive for this specific design. If further analysis indicates that additional measures are required to seal the breech at peak loads, one or more of the following steps can be taken:

- Reduce the breech housing extension by increasing the material strength.

- Reduce the breech housing extension by increasing the housing cross sectional area.

- Increase the seal accommodation by increasing the length of the retaining bolts.

- Increase the seal accommodation by permitting the seal to slide by providing clearance under the bolt heads.

7.5 PRODUCTION COST ESTIMATE

The production cost estimate for the rotating breech automated loader and ammunition handling system is $48,000 per unit, in 1980 dollars, based on a production volume of one thousand units. This estimate is based on the concept drawings, and represents a preliminary estimate for budgetary and planning purposes only.

8.0 RECOMMENDATIONS

This conceptual design program has conceived and evaluated a wide variety of 155mm automated ammunition handling systems, resulting in the preliminary development of the preferred concept described in section 7. Although much remains to be done to develop a functional working system, we believe that this program has established the following conclusions.

1. The rotating breech concept offers distinct advantages inherent to the rotating breech concept, in that it does not require indexing the gun for reload or locating the breech and loading at varying elevation angles. Ammunition is always loaded from the same position without indexing. This results in design simplicity, improved reliability, and improved firing rates.

2. The preferred concept is capable of meeting the basic burst rate of fire requirement of three rounds in ten seconds, and can exceed the sustained firing rate by a wide margin. Additional development is required to demonstrate the ability to meet other design objectives such as the reliability, availability and maintainability targets, however, preliminary evaluation indicates that there are no fundamental reasons why these objectives cannot be met, and that there is a high probability that they could be met with further development.

Based on the above positive conclusions, Chrysler Defense recommends that:

- The development of the rotating breech automated ammunition handling system should be continued, and that this development program should be based on the preferred concept described in section 7 of this report.

- That the development program should be structured to include the following tasks.

  Task 1 - Definition - additional development and analysis of the preferred concept.

  Task 2 - Mock up - Develop a quarter-scale mock-up of the rotating breech portion of the system.

Task 3 - Subsystem development - develop brassboard models of the ammunition handling subsystems.

9.0 PROBLEM AREAS

This contract has resulted in the conceptual design of a loader mechanism capable of automatically loading and firing three rounds in ten second bursts. Much additional definition will be required. However, to translate this conceptual design into functional hardware, some of the primary areas requiring further definition include the following:

<u>Structure Strength</u> -

From the preliminary stress analysis of the breech and breech housing, both need to be structurally strengthened. It may be necessary to re-shape the breech housing to reduce the high bending moments present in the current design. Redesigning these components would also alter many of the other remaining components.

<u>Breech Seals</u> -

Study the feasibility of the breech seal concept to determine the sealing and wear characteristics and the effects of the bore discontinuity at the seal.

Although a similar seal design has been successfully employed on the 20mm M39 gun, the effectiveness of the seal when used with large caliber ammunition and on a curved surface has not been demonstrated.

<u>Primary Assembly</u> -

The primer feed mechanism has not been developed in detail. Additional development is necessary to define this mechanism.

<u>Design details</u> -

Level one drawings were developed to conceptually define the automated loader, however, additional details and development of the breech assembly, locking mechanism and manual back-up systems will be required to develop a functional system.

Stress Analysis -

Additional structural analysis of the detailed components is required to augment the preliminary analysis contained in this report.

Control Logic -

Outline the control logic required to sequence the system and interface with the fire control system.

Ammunition Rack -

Study the gravity feed aspects of the ammunition rack for the ranges of ammunition anticipated, including potential damage to the ammunition.

Resupply Concepts

Further develop re-supply concepts.

APPENDIX A

PRELIMINARY STRESS ANALYSIS

The automated ammunition handling system is mechanically complex and unique and therefore will require major structural analysis of several components. However, the objective here is to establish a reasonable confidence in the proposed concept feasibility and as such only the following will be verified.

(1) Adequacy of breech

(2) Adequacy of breech housing

(3) Determination of mass moment of inertia of breech (for information only)

A.1 Adequacy of breech (see figure 3-9 for breech details)

Load: Breech must withstand 60,000 psi internal pressure (see objective 1.2.1, p 2)

Model: Approximate the breech by a hollow thick-walled cylinder shown below. Solution is given in Table 32, case 1a on page 504 of Ref. 1.

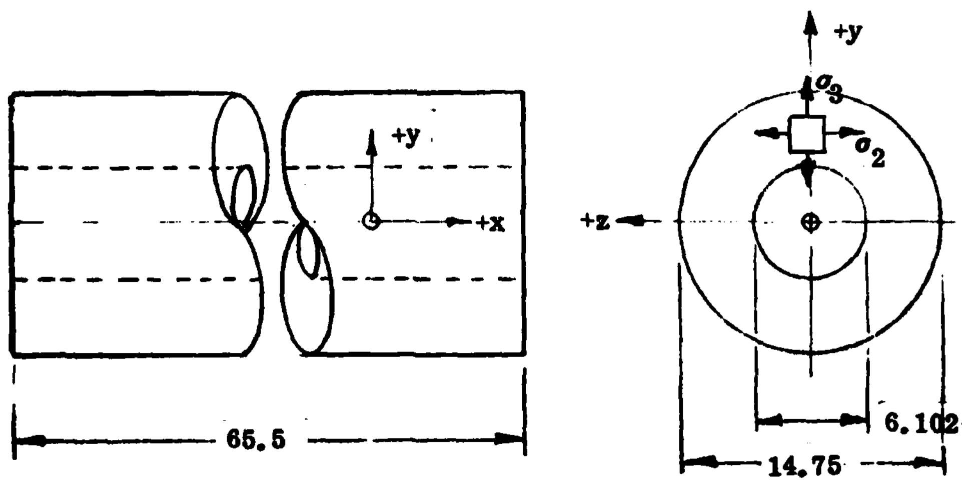

Figure A-1 Breech Model

Given:	a	=	Outer Radius = 14.75/2 = 7.375 in
	b	=	Inner Radius = 155mm/2 = 6.102 in/2 = 3.051 in
	q	=	Internal Pressure = 60,000 psi
	l	=	Tube Length = 65.5 in
	E	=	Elastic Modulus (Steel) = 29 x 10^6 psi
	ν	=	Poisson's Ratio (Steel) = 0.300

Analysis:

Let:

σ_1 = Axial Stress

σ_2 = Tangential Stress

σ_3 = Radial Stress

τ = Shear Stress

σ_1 = 0 (Ignoring inertial, frictional and seal lip forces)

$$\text{Max } \sigma_2 = q \frac{a^2 + b^2}{a^2 - b^2}$$

$$\text{Max } \sigma_3 = -q$$

$$\text{Max } \tau = q \frac{a^2}{a^2 - b^2}$$

Change in length

$$\Delta l = \frac{-q \nu l}{E} \frac{(2b^2)}{(a^2 - b^2)}$$

Substituting values

$$\left.\begin{aligned} \text{Max } \sigma_2 &= (60,000) \frac{(7.375)^2 + (3.051)^2}{(7.375)^2 - (3.051)^2} = \underline{84.8 \times 10^3 \text{ psi}} \\ \text{Max } \sigma_3 &= -60,000 \text{ psi} \\ \text{Max } \tau &= (60,000) \frac{(7.375)^2}{(7.375)^2 - (3.051)^2} = \underline{72.4 \times 10^3 \text{ psi}} \end{aligned}\right\} \quad \text{A.1}$$

$$\Delta l = \frac{-(60,000)\ (.3)\ (65.5)\ (2)\ (3.051)^2}{(29 \times 10^6) \left((7.375)^2 - (3.051)^2\right)} = \underline{-.017 \text{ in}} \quad \text{A.2}$$

Results and Material Selection:

The calculated stresses (equation A.1) are too high to expect this cradle to survive an infinite number of firings barring use of some exotic materials. Increase in breech thickness should be considered. From limited life standpoint, try the following material.

AISI 4340 alloy steel, heat treated to 42-46 Rockwell 'C'. The expected mechanical properties of this material are:

Ultimate tensile strength	195 ksi
Yield strength	180 ksi
Fracture toughness K_{I_c}	50 to 100 ksi $\sqrt{\text{in}}$ (Actual value to be determined by testing)

The actual prediction of number of pressure cycles before a crack initiates, the rate of propagation of crack, the critical crack size and fatigue life calculations must be performed before this stress level and the choice of material can be fully accepted. These calculations are beyond the scope of this preliminary analysis. However, from static considerations only, one could look at maximum energy of distortion theory of failure (von Mises) to determine the maximum equivalent stress, as follows:

$$\sigma_e^2 = \frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}$$

Where σ_e = Equivalent Stress according to von Mises Theory

σ_1, σ_2 & σ_3 = Principal Stresses

In our biaxial stress state, this becomes:

$$\sigma_e = \sqrt{\sigma_1^2 - \sigma_1 \sigma_2 + \sigma_2^2}$$

$$= \sqrt{(84.8)^2 - (84.8)(-60) + (-60)^2}$$

$$\sigma_e = \underline{126 \text{ ksi}} \qquad \text{A.3}$$

σ_e should be less than the yield strength of material. For static analysis viewpoint, the available margin of safety is 180/126 - 1 = 0.43. This factor should be used with caution, however, since it provides no indication of the structural adequacy for successive firings.

A.2 Adequacy of breech housing (see figures 3-10 and 3-11 for details)

Load: Housing must stand 2.5×10^6 lb maximum axial breech force. (see Objective 1.2.1, p 2)

Model: Approximate shape of the housing is shown below for simplified calculations.

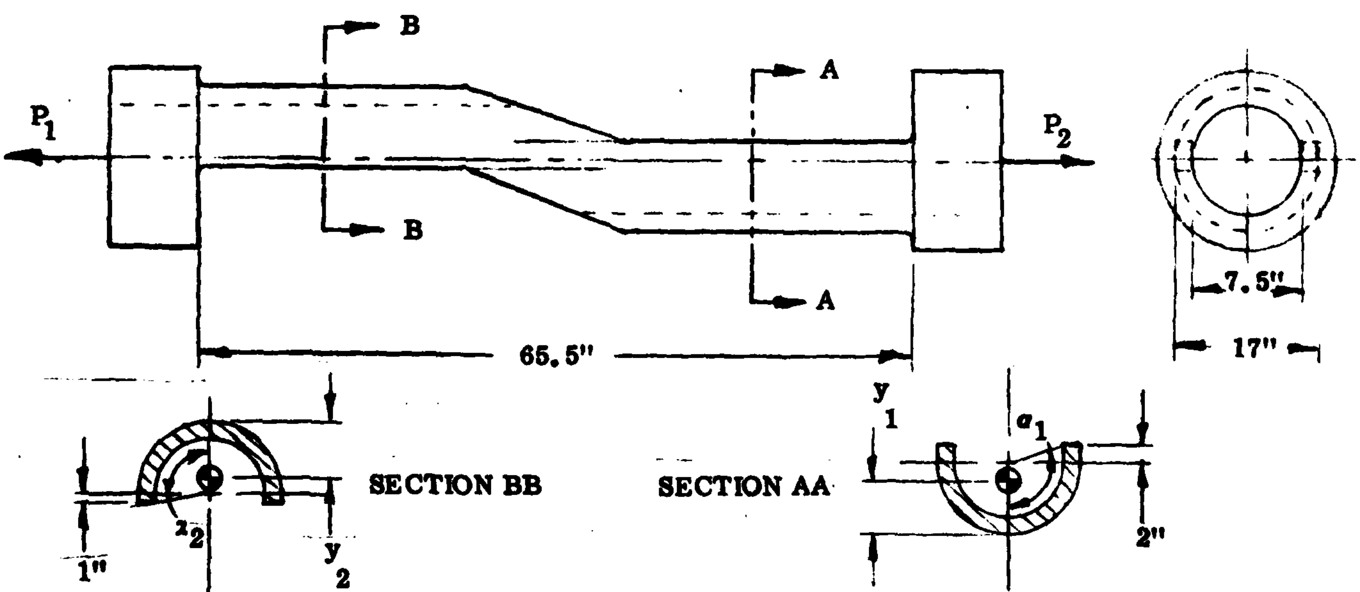

Figure A-2 Breech Housing Model

Analysis:

Let:

P_1 = Applied Force at Aft End

P_2 = Reacted Force at Front End

y_1 = Centroid Location for Section AA

y_2 = Centroid Location for Section BB

R = Outside Radius = 8.5 in

α_1 = Angle to Section AA Edge for I_1

α_2 = Angle to Section BB Edge for I_2

I_1 = Area Moment of Inertia for Section AA

I_2 = Area Moment of Inertia for Section BB

S_1 = Section Modulus of Section AA

S_2 = Section Modulus of Section BB

M_1 = Resulting Moment at Neutral Axis for Section AA

M_2 = Resulting Moment at Neutral Axis for Section BB

t = Uniform Section Thickness

A = Cross Sectional Area

σ_1 = Maximum Stress at Section AA

σ_2 = Maximum Stress at Section BB

Area Moment of Inertia:
(Formulae can be found on p. 69, case 19 of Ref. 1)

Refer to Figure A-2.

$$y_2 = R\left[1 - \frac{2\sin\alpha}{3\alpha}\left(1 - t/R + \frac{1}{2 - t/R}\right)\right]$$

$$I = R^3 t\left[\left(1 - \frac{3t}{2R} + \frac{t^2}{R^2} - \frac{t^3}{4R^3}\right)\left(\alpha + \sin\alpha\cos\alpha - \frac{2\sin^2\alpha}{\alpha}\right) + \frac{t^2\sin^2\alpha}{3R^2\alpha\,(2 - t/R)}\left(1 - \frac{t}{R} + \frac{t^2}{6R^2}\right)\right]$$

$$\alpha_1 = \pi/2 + \mathrm{Arctan}\,\frac{2}{8} = 1.816\ \mathrm{Rad} = 104^\circ$$

$$\alpha_2 = \pi/2 + \mathrm{Arctan}\,\frac{1}{8} = 1.695\ \mathrm{Rad} = 97.1^\circ$$

$$t = 1.0\ \mathrm{in}$$

$$y_1 = 8.5\left[1 - \frac{2 \sin 104^{\circ}}{3 \times 1.816}\left(1 - \frac{1}{8.5} + \frac{1}{2 - 1/8.5}\right)\right]$$

$$= 8.5\left[1 - .356\,(1 - .1176 + .531)\right]$$

$$= \underline{4.223 \text{ in}}$$

$$y_2 = 8.5\left[1 - \frac{2 \sin 97.1^{\circ}}{3 \times 1.695}\left(1 - \frac{1}{8.5} + \frac{1}{2 - 1/8.5}\right)\right]$$

$$= 8.5\left[1 - .3903\,(1 - .1176 + .53125)\right]$$

$$= \underline{3.810 \text{ in}}$$

$$I_1 = (8.5)^3\,(1.0)\left[\left(1 - \frac{3(1)}{2(8.5)} + \frac{(1)^2}{(8.5)^2} - \frac{(1)^3}{4(8.5)^3}\right)\right.$$

$$\left(1.816 + \sin 104^{\circ} \cos 104^{\circ} - \frac{2 \sin^2 104^{\circ}}{1.816}\right)$$

$$\left. + \frac{(1)^2 \sin^2 104^{\circ}}{3(8.5)^2\,(1.816)\,(2 - 1/8.5)}\left(1 - \frac{1}{8.5} + \frac{(1)^2}{6(8.5)^2}\right)\right]$$

$$= 614.125\left[(1 - .1765 + .0138 - .0004)\,(1.816 + (-2.347) - 1.0369)\right.$$

$$\left. + .00127\,(1 - .1176 + .002306)\right]$$

$$= \underline{280.51 \text{ in}^4}$$

$$I_2 = (8.5)^3\,(1)\left[\left(1 - \frac{3(1)}{2(8.5)} + \frac{(1)^2}{(8.5)^2} - \frac{(1)^3}{4(8.5)^3}\right.\right.$$

$$\left(1.695 + \sin 97.1^{\circ} \cos 97.1^{\circ} - \frac{2 \sin^2 97.1^{\circ}}{1.695}\right)$$

$$\left. + \frac{(1)^2 \sin^2 97.1^{\circ}}{3(8.5)^2\,(1.695)\,(2 - 1/8.5)}\left(1 - 1/8.5 + \frac{(1)^2}{6(8.5)^2}\right)\right]$$

$$= 614.125\left[(1 - .1765 + .0138 - .0004)\,(.4104) + .001424\,(1.11764)\right]$$

$$= \underline{211.94 \text{ in}^4}$$

$$S = \frac{I}{\text{distance of neutral axis from innermost edge of section}}$$

$$S_1 = \frac{280.51}{10.5 - 4.223} = \underline{44.69 \text{ in}^3}$$

$$S_2 = \frac{211.94}{9.5 - 3.81 \text{ in}} = \underline{37.25 \text{ in}^3}$$

$$A = \alpha\, t\,(2R - t) \qquad \text{A.4}$$

$$A_1 = 1.816\,(1)\,(2 \times 8.5 - 1) = \underline{29.056 \text{ in}^2}$$

$$A_2 = 1.695\,(1)\,(2 \times 8.5 - 1) = \underline{27.12 \text{ in}^2}$$

Loads:

$$P_1 = 2.5 \times 10^6 \text{ lb}$$

P_2 will be substantially lower than P_1 because of inertia of major portion of recoiling parts will be acting on the front end of housing. However, for simplicity and conservatism, assume

$$P_2 = P_1 = 2.5 \times 10^6 \text{ lb} \quad \text{A.5}$$

$$M_1 = 2.5 \times 16^6 \text{ lb } (8.5 \text{ in} - 4.223 \text{ in}) = 10.6925 \times 10^6 \text{ in. lb}$$

$$M_2 = 2.5 \times 10^6 \text{ lb } (8.5 \text{ in} - 3.810 \text{ in}) = 11.725 \times 10^6 \text{ in. lb}$$

Stresses:

$$\sigma = \text{Bending Stress} + \text{Axial Stress}$$

$$= \frac{M}{S} + \frac{P}{A}$$

$$\sigma_1 = \frac{10.6925 \times 10^6}{44.69} + \frac{2.5 \times 10^6}{29.056} = 325.3 \times 10^3 \text{ psi}$$

$$\sigma_2 = \frac{11.725 \times 10^6}{37.25} + \frac{2.5 \times 10^6}{27.12} = 406.9 \times 10^3 \text{ psi}$$

Change in length $\Delta l = \frac{PL}{AE} = \frac{(2.5 \times 10^6)\ (66.5)}{27.12\ \ 30\ \ 10^6}$

$$\cong .2 \text{ in}$$

Results and Material Selection:

The calculated stresses in the housing (equation A.5) are substantially higher than acceptable. But considering the fact that P_2 should be much less than assumed ize 2.5×10^6 lbs, the actual stresses will be significantly lower than calculated here. These stresses can be further reduced by reconfiguring the housing to minimize bending loads.

A.3 Mass moment of inertia for the breech

I = Breech Mass Moment of Inertia about z - axis

R_o = Outside Radius of Breech = $\frac{14.75}{2}$ = 7.375 in

R_i = Inside Radius of Breech = $\frac{6.102}{2}$ = 3.051 in

l = Length of Breech = 65.5 in

= Mass Density (of Steel) = .29 lb/in^3

M_o = Mass of Solid Cylinder of Radius R_o

M_i = Mass of Solid Cylinder of Radius R_i

$$I = \frac{1}{12} M_o \left(3R_o^2 + l^2\right) - \frac{1}{12} M_i \left(3R_i^2 + l^2\right)$$

$$M_o = \frac{\pi}{4} (14.75)^2 (65.5) (.29) = 3246 \text{ lb}$$

$$M_i = \frac{\pi}{4} (6.102)^2 (65.5) (.29) = 555 \text{ lb}$$

$$I = \frac{1}{12} (3246) \left[(3 (7.375)^2 + (65.5)^2\right]$$

$$- \frac{1}{12} (555) \left[(3 (3.051)^2 + (65.5)^2\right]$$

$$= 1.005 \times 10^6 \text{ lb-in}^2 = \frac{1.005 \times 10^6}{(32.2)(12)^2} = \underline{216.7 \text{ slug-ft}^2} \qquad \text{A.6}$$

References:

1. Roark R., Young W., "Formulas for Stress and Strain," 5th Ed., McGraw-Hill

APPENDIX B

Parts List - Single Axis Rotating Breech

NO	NAME	QTY	APPLICATION DESCRIPTION
	Rotary Actuator-Hyd	1	P/N SP-5076
			Ex-Cell-O Corporation
			Greenville, Ohio
	Control Circuit	1	P/N SK-1509
			Cadillac Gage Division
			Hydraulic Products
			Ex-Cell-O Corporation
			Greenville, Ohio
	Elevation Trunnion Bearing	2	P/N 35SF56
			Torrington Company
			Bearing Division
			Torrington, Conn. 06790
	Breech Trunnion Bearing	1	P/N 15SF24
			Torrington Company
			Bearing Division
			Torrington, Conn 06790
	Guide Bearing	4	P/N LBB-2000
			Heim Universal Co.
			Fairfield, Conn.
	Guide Bearing	4	P/N LBB-2000-PP
			Heim Universal Co.
			Fairfield, Conn.
	Snap Ring	4	MS16631-1300
	Solenoid	1	F12001058 or F7791685
			Note: Mounting modification required

Parts List - Single Axis Rotating Breech

NO	NAME	QTY	APPLICATION DESCRIPTION
	Breech Sleeve	1	L.O. 12677-8
1	Breech	1	L.O. 12677-6 Fig. 3-9
2	Guide	2	L.O. 12677-6 Fig. 3-9
1	Pads, Gun Tube	4	L.O. 12677-9 Fig. 3-16
2	Torque Bar Housing	1	L.O. 12677-9 Fig. 3-16
3	Pads, Recoil Piston	6	L.O. 12677-9 Fig. 3-16
4	Bracket Assy	1	L.O. 12677-9 Fig. 3-16
5	Anchor Assy	1	L.O. 12677-9 Fig. 3-16
5	Torque Bar Mtg. Pad	1	L.O. 12677-5 Fig. 3-10
7	Latch Cover	1	L.O. 12677-5 Fig. 3-10
8	Bracket, Pivot	1	L.O. 12677-5 Fig. 3-10
9	Arm, Piston-Recoil	1	L.O. 12677-5 Fig. 3-10
12A	Key, Circular Male	1	L.O. 12677-5 Fig. 3-10
12B	Key, Circular Female	1	L.O. 12677-5 Fig. 3-10
13A	Forward Breech Guide	1	L.O. 12677-5 Fig. 3-10
13B	Rear Breech Guide	1	L.O. 12677-5 Fig. 3-10
1	Dowel	2	L.O. 12677-4 Fig. 3-11
2	Dowel	1	L.O. 12677-4 Fig. 3-11

Parts List - Single Axis Rotating Breech

NO	NAME	QTY	APPLICATION DESCRIPTION
3	Bracket Assy	1	L.O. 12677-4 Fig. 3-11
10	Lock Bolt	2	L.O. 12677-4 Fig. 3-11
11	Hold Down Bolt	2	L.O. 12677-4 Fig. 3-11
1	Breech Housing	1	L.O. 12677-3 Fig. 3-15
2	Locking Wedge	1	L.O. 12677-3 Fig. 3-15
3	Cradle Mtd. Brace	1	L.O. 12677-3 Fig. 3-15
5	Primer Assy	1	L.O. 12677-3 Fig. 3-15
7	Pin, Stabilizing	1	L.O. 12677-3 Fig. 3-15
8	Pin, Pivot	1	L.O. 12677-3 Fig. 3-15
9	Pawl Assy	1	L.O. 12677-3 Fig. 3-15
10	Actuating Rod	1	L.O. 12677-3 Fig. 3-15
11	Stop	1	L.O. 12677-3 Fig. 3-15
12	Primary Wedge	1	L.O. 12677-3 Fig. 3-15
13	Locking Spring	1	L.O. 12677-3 Fig. 3-15
14	Actuating Pin	1	L.O. 12677-3 Fig. 3-15
15	Holding Pin	1	L.O. 12677-3 Fig. 3-15
16	Interrupter Pin	1	L.O. 12677-3 Fig. 3-15
17	Retaining Plate	1	L.O. 12677-3 Fig. 3-15

Parts List - Single Axis Rotating Breech

NO	NAME	QTY	APPLICATION DESCRIPTION
	Replenisher	1	Figure 3-13
	Valve, 2 Position	1	Figure 3-13
	Valve, 3 Position	1	Figure 3-13
	Accumulator	1	Figure 3-13
	2" Ø Line	As Req.	Figure 3-13
	3/4" Ø Line	As Req.	Figure 3-13
	Check Valves	2	Figure 3-13
	Electrical Cable	As Req.	
3	Torque Bar Assy	1	L.O. 12677-1 Fig. 3-8

APPENDIX C

Parts List - Guided Ramp Conveyor

NO	NAME	QTY	APPLICATION DESCRIPTION
1	LH Shuttle Assy	1	
2	RH Shuttle Assy	1	
3	Hydraulic Cyl	2	2 1/2 Bore 3.0 Stroke Med. Duty
4	Brkt.	2	Cyl. Mounting
5	Hydraulic Cyl.	2	2 1/2 Bore 8 1/2 Stroke Med Duty
6	Brkt.	2	Cyl. Mounting
7	CAM Follower	24	2.0 Dia. 1.0 Wide
8	Lever L.H.	2	
9	Operating Rod Long	4	
10	Lever L.H.	2	
11	Shuttle (Weldment)	2	
12	Leve .H.	2	
13	Lifting Rack	6	
14	Mount (Weldment)	2	Lifts Detail 13
15	Lever R.H.	2	
16	Operating Rod Short	4	
17	Lever R.H.	2	
18	Lever R.H.	2	
19	Hydraulic Cyl.	2	1 1/2 Bore 1 3/4 Stroke Med Duty
20	Connecting Rod	2	
21	Spring	64	
22	Spring Keeper	64	
23	Lever	162	
24	Shaft	64	
25	Latch	10	
26	Spring (Latch)	10	
27	Lever (Latch)	10	
28	Lever	10	
29	Lever Pickup	10	
30	Shaft	10	
31	Spring (Pickup Lever)	10	
32	Lever	10	
33	Brkt. Rear	12	Lengths Very
34	Brkt. Ctr.	12	Lengths Very
35	Brkt. Front	12	Lengths Very
36	CAM Follower	6	1 1/2 Dia. 1.00 Wide

Parts List - Guided Ramp Conveyor

NO	NAME	QTY	APPLICATION DESCRIPTION
37	Upper Mounting Brkt.	1	
38	Pully	4	
39	RAM Assy	1	
40	Universal Joint	2	
41	Drive Shaft	1	
42	Cable Assy	2	
43	Hydraulic Motor	2	
44	Motor Mounting Brkt.	1	
45	Gear Box	1	
46	Take-Up Drums	2	Spring Clutch Control Req'd
47	Ramp	1	
48	Hydraulic Cyl.	2	2.00 Bore 3.0 Stroke
49	Spring	4	
50	Clamp L.H.	1	
51	Bearing	3	
52	Cradle L.H.	1	
53	Clamp R.H.	1	
54	Cradle R.H.	1	
55	Bearing	2	
56	Support	2	
57	Hydraulic Cyl.	1	2.50 Bore 15" Stroke Med Duty
58	Mounting Brkt.	1	